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LAMINATION OF NONWOVENS WITH NANOFIBROUS LAYER

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STATEMENT

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God's Spirit joins Himself to our spirit to declare that we are God's children (Romans 8:16). I wish to express my sincere gratitude to my CREATOR, God for the love and guidance He showed me throughout my studies and the opportunity He gave me to be in this position, Jesus Christ is a soul-winner. That is what He came for, lived for, died for and rose again for "NGIYABONGA BABA"

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I want to dedicate this work to my late biological parents, Samuel Sipho Nkosi and Ntobeko Shezi if you were not with me, I won't be this far.

ABSTRACT

The aim of this research was to develop new material using spun bond (polypropylene and polyethylene) and nanofiber materials (polyacrylonitrile) which can result to nonwoven fabric with very specific properties that are characterized by very soft and pleasant feel, excellent, comfortable properties upon contact with human skin section and higher elasticity.

This research will be also setting new standards for hygienic applications (baby diapers, feminine hygiene and incontinence products). This will be a greater opportunities for bonding (polyethylene) with other fabrics for composite materials in the automotive industry or in construction.

The steps that will be used to achieve all this properties .(i) The first route to achieve all this is to form bicomponent nonwoven fabric through lamination machine, where we will be laminating spunbond materials and nanofibers materials.(ii) The second route is to do tests to this samples, through controlling some parameters. First test will be comparing the penetration and efficiency for each sample using Sodium Chloride Filter instrument. The second test will be comparing the strength of joint for each sample using a tensile tester, also known as a tension test. The third and the last test will be finding the bending length to determine the flexural rigidity for each sample and compare them. The last route of this research will be using SEM analysis to show how fibers are arranged after lamination.

CONTENTS

ABBREVIATIONS

Cm	: Centimeter
g/m^2	: Grams per square area
mgm	: Milligram metre
µm	: Micrometer
m/min	: Metre per minute
^0C	: Degrees Celsius
Kg/m^2	: Mass per square area
A	: Area of the specimen
C	: The mean of bending length
CD	: Cross machine direction/Transverse direction
G_{MD}	: Flexural rigidity of machine direction
G_{CD}	: Flexural rigidity of cross machine direction
MD	: Machine direction/Longitudinal direction
PP	: Polypropylene fibre
PE	: Polyethylene fibre
PAN	: Polyacrylonitrile
NF	: Nanofibrous layer
SB	: Spun bond material
W	: Weight of the sample in grams per square area
Sample 1	: A, B, C, D, E, F, G, H
Sample 2	: A', B', C', D', E', F', G', H'
Sample 3	: A", B", C", D", E", F", G", H"
Sample 4	: 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17

1 Introduction

1.1 Definition of nonwovens and the manufacture

The manufacture of nonwovens has expanded rapidly and the use of such products has penetrated many aspects of industry and private life. Nonwovens are found in hygiene and health care, in rooting and civil engineering, household and automotive, in cleaning, filtration, clothing, food wrap and packaging, to name only a few end-uses [2]. Confusion or ignorance about nonwovens remains large though. The present project comes out therefore at the right time to give a comprehensive view of what is to be understood by nonwovens, their manufacturing process and possibilities. Presenting in a coherent way the present state of the art of nonwovens manufacturing and end-uses will be an invaluable help to all those within the industry or outside of it who deal with nonwovens or might get the opportunity to do so [1].

It is to be hoped that this project will also have a seminal influence in attracting young talents to this growing industry, where so much still is needed in order to further develop machinery, raw materials and properties of nonwovens to their best use.

Nonwoven fabrics are flat, flexible, porous sheet structures that are produced by interlocking layer or networks of fibers, filaments, or film-like filamentary structures. The three categories of raw materials used to produce a nonwoven fabric are: Fibers, Binders and Additives [4].

Fibers are the basic units of a nonwoven structure. Consequently, much of the utility properties and performance of a nonwoven is due to the fibers used. A fiber has been defined as any substance, natural or manmade, with a high length-to-width ratio and with suitable characteristics for being processed into a fabric [2].

A wide range of fiber types, both synthetic and natural, has been employed in the production of nonwoven products. It is very likely that every fiber known to mankind has been used in a nonwoven structure at one time or another [6]. However, commercially important nonwoven fabrics have been limited to relatively few fiber types, in view of the large that are available.

The dominant fibers include polypropylene, polyester and rayon. Between them these three fiber types made up a substantial part of the overall nonwoven market for fibers. In Western Europe, for example, the three siteing for nearly 70% of staple fiber consumption by the nonwovens industry [5].

For many years, almost all nonwovens required a chemical binder in order to provide any measure of structural integrity [3]. In addition, the binder was called upon to contribute and convey numerous properties that were necessary for the effective performance of the fabric.

In the very early stages of nonwoven development, different types of natural resins and glues were used to bond nonwovens [4]. Later on, synthetic binders were developed to meet the structural and performance requirements of nonwoven fabrics.

Adding a latex binder can be a cost-effective way of consolidating a fiber web and achieving specific properties [8]. It often results that adding a latex binder can be done at a lower cost than using a special binder fiber. In many cases, there can be a combination of chemical binder with mechanical and thermal bonding techniques, affording the finished fabric properties that would be impossible to achieve otherwise. Furthermore binder systems can accept pigments and dyes, so they can often help in adding colour to nonwoven fabrics [1].

Many non-fibrous materials are used in the manufacture, bonding and finishing of nonwoven webs. Many of these are applied in one form or another to the preformed web usually after bonding and as a secondary process. Additive materials which are properly classified as raw materials are those added to the fibre or filament structure during web laydown and might include thermally active powders and absorbents [3].

The term used to designate the products generally known as nonwovens, was coined in most languages in opposition to woven fabrics, which implicitly were taken as a reference. Only specialists know that nonwovens are unique engineered fabrics which offer cost effective solutions as e.g. in hygiene convenience items, or as battery separators, or filters, or geotextiles, etc.

A nonwoven was something that was not woven. Nonwoven is defined as a manufactured sheet, web or batt of directionally or randomly oriented fibers, bonded by friction, and / or cohesion and/ or adhesion, excluding paper and products which are woven, knitted, tufted,

stitch bonded incorporating bonding yarn, or felted by wet-milling whether or not additionally needled [2]. The fibers may be of natural or man-made origin and may be staple or continuous filaments.

As a main characteristic the CEN definition indicates that a nonwoven is a fabric made of fibres that is consolidated in different ways [2]. Nonwoven fabrics are made out of fibres, without any restriction, but not necessarily from fibres. These can be very short fibres of a few millimeters length as in the wetlaid process; these can be "ordinary" fibres, as used in the traditional textile industry, or then very long filaments etc. Properties and characteristics of a nonwoven fabric depend for a large part from the type of fibre it is ultimately made off. These fibres can be natural or man-made, organic or inorganic; the characteristic of a fibre being that it is longer than its thickness, or diameter [7]. Such fibres can also be produced continuously in connection with the nonwoven process itself and then cut to length, or then extruded directly e.g. from polymer granules into a filament and then fibrous structure.

To make good measure the ISO definition also excludes various types of fabrics to which, voluntarily or not, one might compare nonwovens [8]. Nonwovens are not paper and indeed, when made out of very short, cellulose fibres, they essentially differ from paper because there aren't any, or hardly, hydrogen bonds linking such fibres together. Some will remark that other textile fabrics were created in the past besides the weaving and knitting process, e.g. felting (which is also yarnless) or more recently stitchbonding. For this reason as well – especially in the early days – some have tended to literally classify as nonwovens all textile fabrics that are outside the weaving/knitting domain. Matters have settled since then and the reflexions at ISO and CEN helped clarify this [7]. As far as textiles go, nonwovens are only part of a category of fabrics that exist besides weaving and knitting.

Nonwovens though go also beyond the limits of textiles. Fibres they ultimately are made of can be very short "unspinnable" ones like in the paper industry; the fibrous web can also originate from foils and other plastics. Nonwovens therefore share for a part manufacturing characteristics and properties with the paper industry or the chemicals/plastics industry to finally make a world of their own. Nonwovens do not depend on the interlacing of yarn for internal cohesion [7]. Intrinsically they have neither an organized geometrical structure. They are essentially the result of the relationship between one single fibre and another. This

provides nonwoven fabrics with characteristics of their own, with new or better properties (absorption, filtration) and therefore opens them up to other applications.

Nonwoven manufacture starts by the arrangement of fibres in a sheet or web. The fibres can be staple fibres packed in bales or filaments extruded form molten polymer granules. There are three main routes to web forming:

- the drylaid system with carding or airlaying as a way to form the web;
- the wetlaid system;
- the polymer-based system, which includes spunlaying (spunbonding) or specialized technologies like meltblown, or flashspun fabrics etc.

1.2 Technologies of nonwovens web forming

Carding is a mechanical process, which starts with the opening of bales of fibres which are blended and conveyed to the next stage by air transport. The fibres are then combed into a web by carding machine, which is a rotating drum or series of drums covered in fine wires or teeth [2]. The precise configuration of cards will depend on the fabric weight and fibre orientation required [6]. The web can be parallel-laid, where most of the fibres are laid in the machine direction, or they can be random-laid [1]. Typical parallel-laid carded webs result in good tensile strength, low elongation and low tear strength in the machine direction and the reverse in cross direction [3]. Relative speeds and web composition can be varied to produce a wide range of properties.

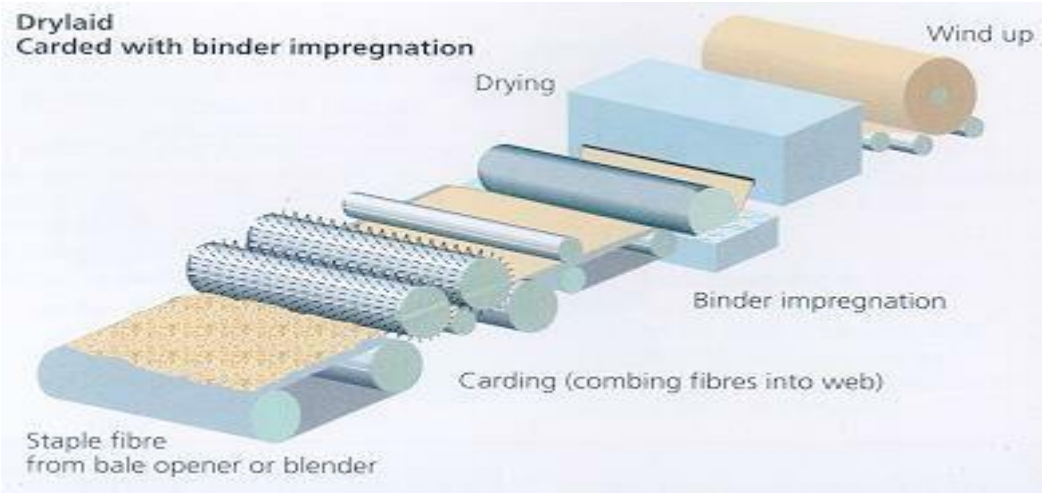


Diagram 1(a).Drylaid, Carded with binder impregnation [3]

The second method of drylaying is airlaying. In airlaying, the fibres, which can be very short, are fed into an air stream and from there to a moving belt or perforated drum, where they can form a randomly oriented web [2]. Compared with carded webs, airlaid webs have a lower density, a greater softness and an absence of laminar structure. Airlaid webs offer great versatility in terms of the fibre blends that can be used.

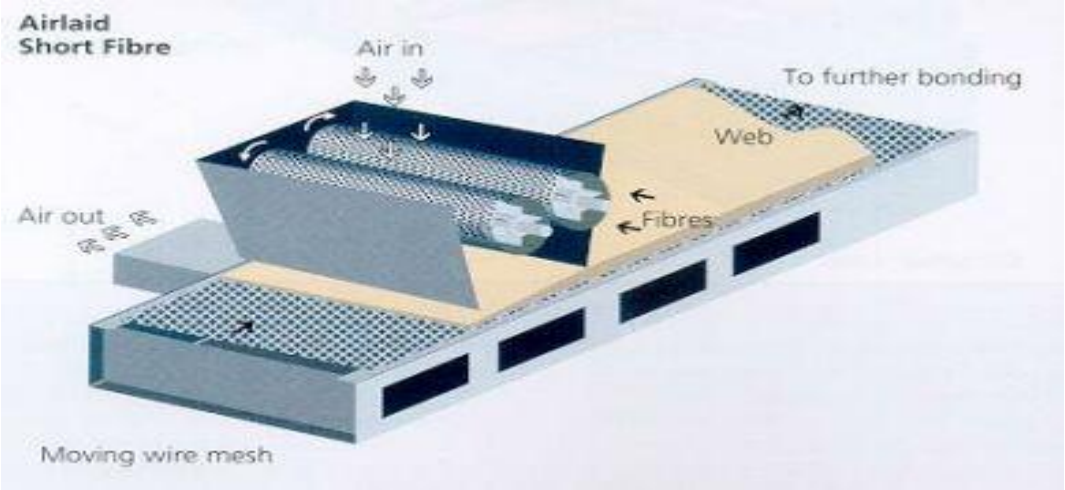


Diagram 1(b): Shows the Airlaid short fibre machine [3].

In Spunlaid process polymer granules are melted and molten polymer is extruded through spinnerets. The continuous filaments are cooled and deposited on to a conveyer to form a uniform web [2]. Some remaining temperature can cause filaments to adhere to one another, but this cannot be regarded as the principal method of bonding. The Spunlaid/Meltblown process (sometimes known as spunbonded) has the advantage of giving nonwovens greater strength, but raw material flexibility is more restricted [3].

Co-extrusion of second components is used in several Spunlaid processes [3], usually to provide extra properties or bonding capabilities. In meltblown web formation, low viscosity polymers are extruded into a high velocity air stream on leaving the spinneret [2]. This scatters the melt, solidifies it and breaks it up into a fibrous web.

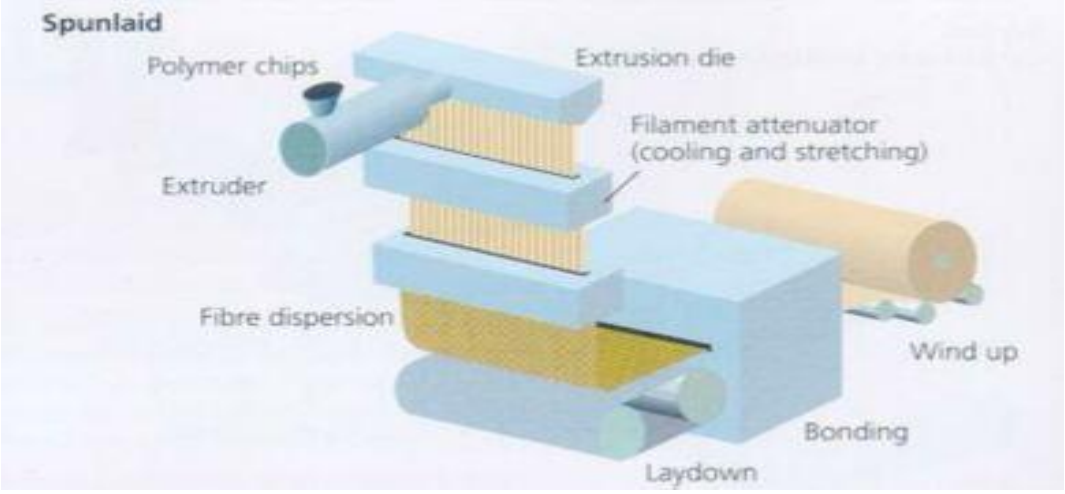


Diagram 1(c): Shows the Spunlaid/Meltblown machine [3].

Dilute slurry of water and fibres is deposited on a moving wire screen and drained to form a web. The web is further de-watered, consolidated, by pressing between rollers and dried. Impregnation with binder is often included in a later stage of the process [6]. Wetlaid web forming allows a wide range of fibre orientations ranging from near random to near parallel [2]. The strength of the random oriented web is rather similar in all directions in the plane of the fabric. A wide range of natural, mineral, synthetic and man-made fibres of varying lengths can be used.

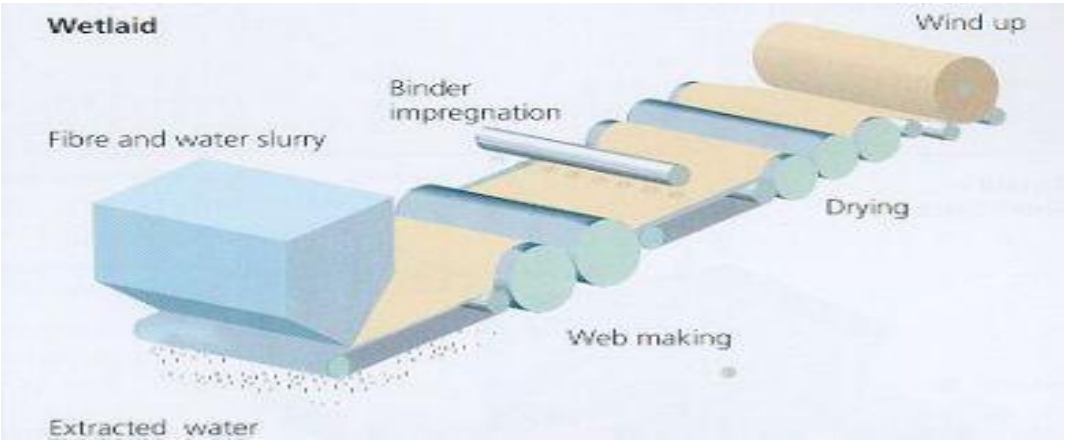


Diagram 1 (d): Shows the Wetlaid machine [3].

The lack of sufficient frictional forces however has to be compensated for by the bonding of the fibres, which provides web strength. Consolidation of the web after its formation is the second step in the nonwoven manufacturing process. This consolidation for a large part sets the final characteristics of the fabric and therefore, if possible, ought to be chosen with the end application in mind. Such consolidation can be done by use of chemical means (chemical bonding) like binders [7]. These can be applied uniformly by impregnating, coating or spraying or intermittently, as in print bonding. The consolidation can also be reached by thermal means (cohesion bonding), like the partial fusion of the constituting fibres or filaments [8]. Such fusion can be achieved e.g. by calendaring or through-air blowing or by ultra-sonic impact.

1.3 Technology of nonwovens bonding

Finally, consolidation can be achieved by mechanical means (frictional bonding), like needling, stitching, water-jet entangling or a combination of these various means [9]. Customers' needs can be further met by modifying or adding to the existing properties of the fabric through finishing. A variety of chemical substances can be employed before or after bonding or various mechanical processes can be applied to the nonwoven in the final stage of the manufacturing process. The choice of the raw material and the final constituting fibrous element, the depositing of the fibres as a fibrous material of a varying density, the choice of consolidating and finishing means, all this creates a series of parameters which can be played with in order to reach the required properties. This also confirms that when ingredients, web formation and consolidation are chosen in order to best meet the characteristics needed at the end application, and then for sure, we have a winner.

Webs, other than spunlaid, have little strength in their unbonded form [2]. The web must therefore be consolidated in some way. This is affected by bonding, a vital step in the production of nonwovens. The choice of method is at least as important to ultimate functional properties as the type of fibre in the web. There are three basic types of bonding: Chemical, Thermal and Mechanical.

Chemical bonding mainly refers to the application of a liquid based bonding agent to the web. Three groups of materials are commonly used as binders, acrylate polymers, styrene-butadiene copolymers and vinyl acetate copolymers [4]. Water based systems are the most widely used but powdered adhesives, foam and in some cases organic solvent solutions are also found.

There are many ways of applying the binder. It can be applied by impregnating, coating or spraying or intermittently, as in print bonding [2]. Print bonding is used when specific patterns are required and where it is necessary to have the majority of fibres free of binder for functional reasons.

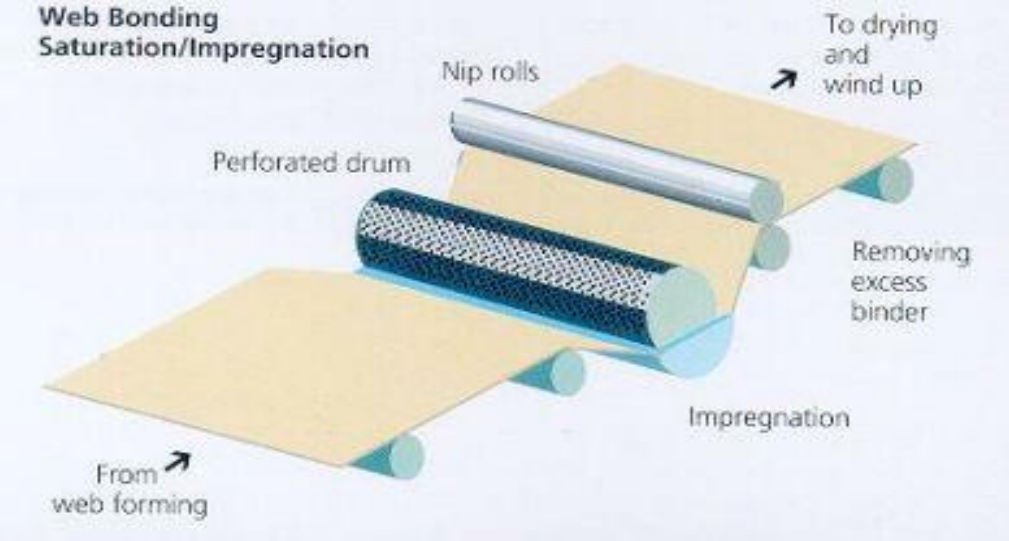


Diagram 2 (a): Shows the Chemical web bonding machine [3].

This method uses the thermoplastic properties of certain synthetic fibres to form bonds under controlled heating [3]. In some cases the web fibre itself can be used, but more often a low melt fibre or bi-component fibre is introduced at the web formation stage to perform the binding function later in the process. There are several thermal bonding systems in use.

Calendaring uses heat and high pressure applied through rollers to weld the fibre webs together at speed [2]. Through-air thermal bonding makes bulkier products by the overall bonding of a web containing low melting fibres. This takes place in a carefully controlled

hot air stream. Drum and blanket systems apply pressure and heat to make products of average bulk.

Sonic bonding takes place when the molecules of the fibres held under a patterned roller are excited by high frequency energy [2], which produces internal heating and softening of the fibres.

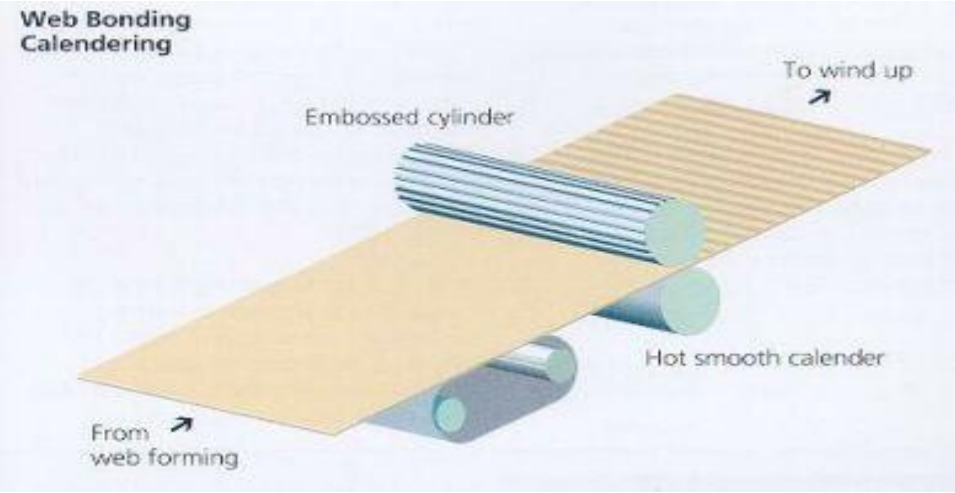


Diagram 2 (b): Shows the thermal web bonging machine [3].

In mechanical bonding the strengthening of the web is achieved by inter-fibre friction as a result of the physical entanglement of the fibres. There are two types of mechanical bonding: needle punching and hydro-entanglement [1]. Needlepunching can be used on most fibre types. Specially designed needles are pushed and pulled through the web to entangle the fibres. Webs of different characteristics can be needled together to produce a gradation of properties difficult to achieve by other means [2]

Hydro-entanglement is mainly applied to card or wetlaid webs and uses fine, high pressure jets of water to cause the fibres to interlace [6]. Hydro-entanglement is sometimes known as spunlacing, as the arrangement of jets can give a wide variety of aesthetically pleasing effects. The water jet pressure used has a direct bearing on the strength of the web, but system design also plays a part [5].

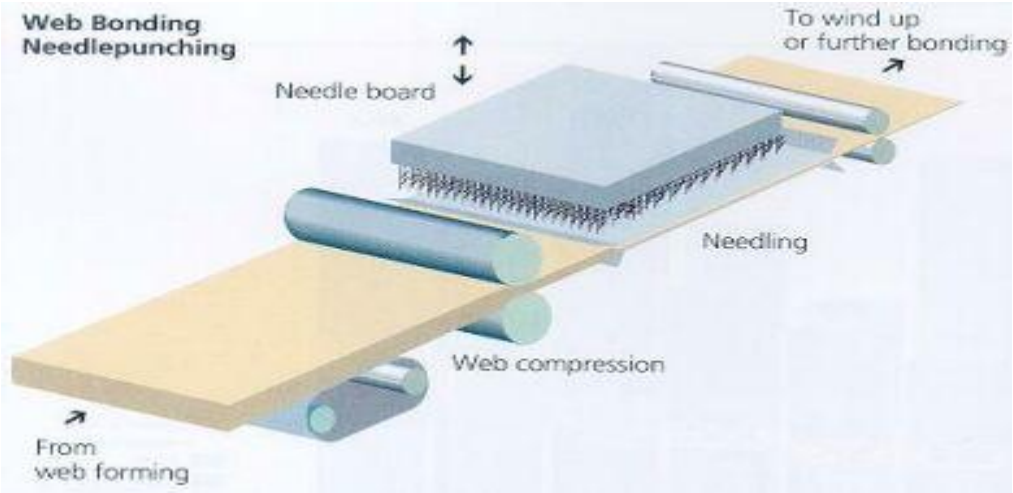


Diagram 2 (c): Shows the mechanical bonding machine [3]

1.4 The nonwovens applications

Nonwovens are in fact products in their own right with their own characteristics and performances, but also weaknesses. They are around us and one uses them everyday, often without knowing it. Indeed they are frequently hidden from view. Nonwovens can be made absorbent, breathable, drapeable, flame resistant, heat sealable, light, lint-free, moldable, soft, stable, stiff, tear resistant, and water repellent, if needed. Obviously though, not all the properties mentioned can be combined in a single nonwoven, particularly those that are contradictory. Their applications are multifold.

2 Bicomponent Fibers

2.1 Definition of bicomponent fibers

Bicomponent fibers can be defined as extruding two polymers from the same spinneret with both polymers contained within the same filament. The core in skin/core fibres is not always to be found exactly at the centre or indeed in the same position over the whole length of the fibre. This likewise creates a tension in the fibre, which results in crimping. Far more important, however, is the fact that bicomponent fibre spinning technology enables polymers with different properties to be spun together, thereby producing fibres with a polyester core and polyamide skin, for example. In such a case, the core guarantees the dimension stability of the fibre and the skin ensures that the fibre will dye easily and well.

The properties of bicomponent fibres are governed by:

- the two raw materials
- the relative quantities of the two components
- their arrangement within the fibre
- the thickness of the fibre

2.2 The technology of bicomponent

Diagram 3 below gives a schematic representation of how bicomponent fibres are produced and explains how it, is in fact possible to mix polymers in such a way as to make fibres other than the bicomponent fibres described. If for example, the melting points of the polymers being mixed are different, the component which melts at a higher temperature will solidify in the still-molten mass of the other polymer, which will set at a lower temperature.

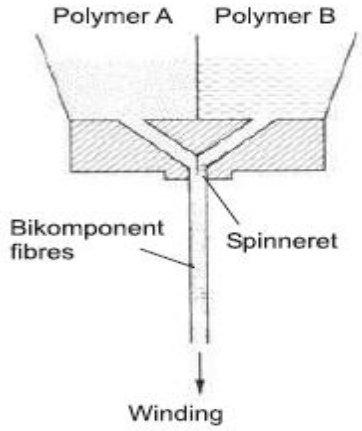


Diagram 3.Bicomponent Fibres production process [11]

When the fibres are drawn, elongated inclusions are formed (Diagram 4). These may even be endless, i.e., they are present in the matrix as very fine filaments. Such fibres are exceptionally stiff and display special physical and chemical properties. Especially in the case of nonwovens, bicomponent fibres open up new fields of application in which particularly large fibre surfaces in relation to their mass per unit area are required. Although relatively fine fibres can be manufactured for this purpose, they are practically impossible to handle at thicknesses of less than approx. 0.5 dtex. For this reason, spinning begins with bicomponent fibres with a total denier that supports the reliable production of fabrics, followed by the splitting of bicomponent fibres into their individual components through chemical or physical processes.

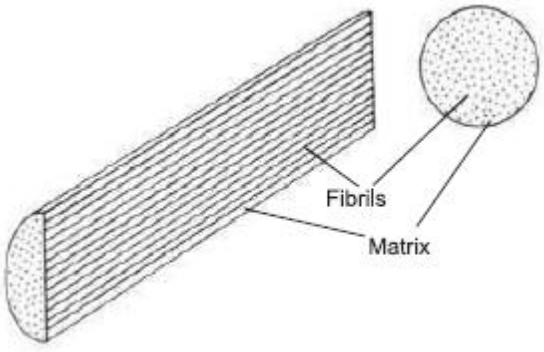


Diagram 4: Bicomponent fibre with fibrils of indefinite length in a matrix. [3]

Ultrafine fibres are made by removing the matrix which holds the individual fibres together (Diagram 5). These ultrafine fibres are similar in form to skin fibrils and can therefore be used in the manufacture of artificial poromeric leathers.

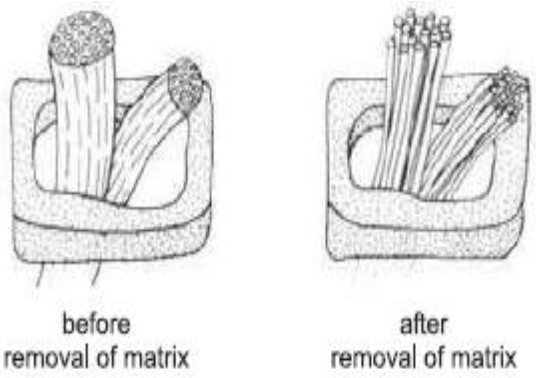


Diagram 5: Bicomponent fibre bundles of ultrafine fibres [6]

Other man-made fibres can also be produced by this method, which works most easily with melt-spun fibres. Another way of modifying polyamide fibres is to vary the number of amino end groups in the macromolecule. If the two molecules 'A' and 'B' (see below) do not combine to form the amide group, the 'free ends' must be saturated in some way.

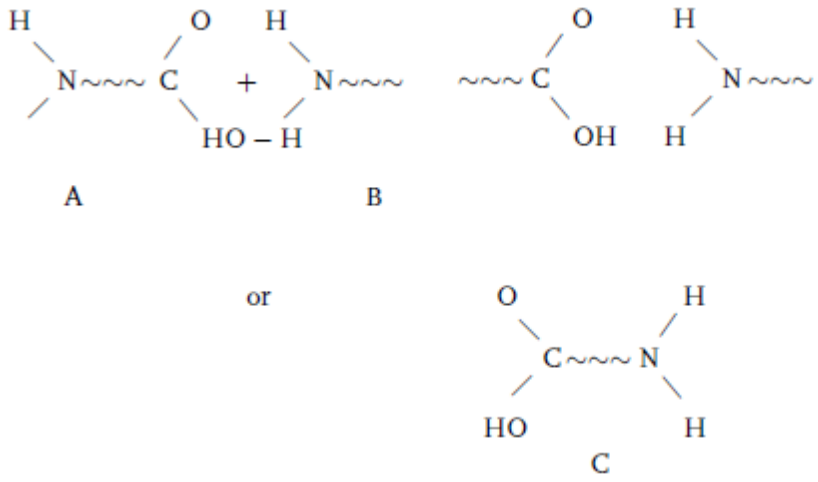


Diagram 6. Way of modifying polyamide fibres is to vary the number of amino end groups in the macromolecule [10]

This can be done with water, for example, resulting in a molecule with an amino group at one end and a carboxyl at the other, as in C below. The amino group is reactive, and it is well known for binding acidic dyes and other such textile auxiliaries. In the case of polyamide 6.6, which is formed from hexamethyldiamine (with one of these amino end groups at either end) and adipic acid, some of the molecules must have one or even two amino end groups [10]. The number of amino end groups depends on the length of the molecule; but since in practice minimum and maximum molecule lengths are required for the manufacture of fibres, the direct addition of substances with amino end groups will also affect the reaction of fibres with specific dyestuffs (chemicals). The affinity to acidic dyes can thus be increased (deep type), reduced (light type), and even blocked (nontype) [11]. This makes differential dyeing possible, i.e., the use of such fibres in combination with others which have a 'normal' affinity to dyestuffs.

A close relative is co-spun fiber, which is a group of filaments of different polymers, but a single component per filament, spun from the same spinneret. [2]

DuPont Company introduced the first commercial bicomponent application in the mid-1960s. This was a side-by-side hosiery yarn called cantrese and was made from two nylon polymers, which, on retraction, formed a highly coiled elastic fiber. In the 1970s, various bicomponent fibers began to be made in Asia, notably in Japan [11]. The term conjugate fiber is often used, particularly in Asia, as synonymous with bicomponent fibers. Very complex and expensive spin packs apparently were used in the manufacturing process. These techniques were found to be technically unsatisfactory and excessively expensive. Later in 1989, a novel approach was developed using thin flat plates with holes and grooves to route the polymers. This process was very flexible and quite price effective [2]. The polymers given below can be used as either of the components in the cross sections [3].

2.3 The most common bicomponent fibers

PET (polyester)	PEN polyester
Nylon 6,6	PCT polyester
Polypropylene	PBT polyester
Nylon 6	co-polyamides
Polylactic acid	polystyrene
Acetal	polyurethane
Soluble co-polyester	HDPE, LLDPE

The main objective of producing Bicomponent fibers is to exploit capabilities not existing in either polymer alone [3]. By this technique, it is possible to produce fibers of any cross sectional shape or geometry that can be imagined. Bicomponent fibers are commonly classified by their fiber cross-section structures as side-by-side, sheath-core, islands-in-the-sea and citrus fibers or segmented-pie cross-section types [6].

Sheath-core bicomponent fibers are those fibers where one of the components (core) is fully surrounded by the second component (sheath) (see diagram.3). Adhesion is not always essential for fiber integrity. This structure is employed when it is desirable for the surface to have the property of one of the polymers such as luster, dyeability or stability, while the core may contribute to strength, reduced cost and the like [6]. A highly contoured interface between sheath and core can lead to mechanical interlocking that may be desirable in the absence of good adhesion.

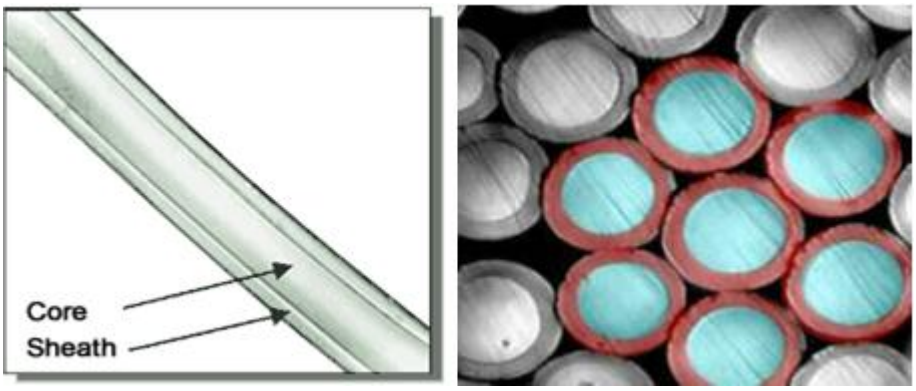


Diagram 7 Cross section and longitudical section of sheath-core bicomponent fibers [6]

The most common way of production of sheath-core fibers is a technique where two polymer liquids are separately led to a position very close to the spinneret orifices and then extruded in sheath-core form (diagram 3). In the case of concentric fibers, the orifice supplying the core polymer is in the center of the spinning orifice outlet and flow conditions of core polymer fluid are strictly controlled to maintain the concentricity of both components when spinning.

Eccentric fiber production is based on several approaches: eccentric positioning of the inner polymer channel and controlling of the supply rates of the two component polymers [6], introducing a varying element near the supply of the sheath component melt [4], introducing a stream of single component merging with concentric sheath-core component just before emerging from the orifice and deformation of spun concentric fiber by passing it over a hot edge [2]. Other, rather different techniques to produce sheath-core fibers are coating of spun fiber by passing through another polymer solution [9] and spinning of copolymer into a coagulation bath containing aqueous latex of another polymer [3]. Modifications in spinneret orifices enable one to obtain different shapes of core or/and sheath within a fiber cross-section. There is considerable emphasis on surface tensions, viscosities and flow rates of component melts during spinning of these fibers.

Besides the sheath-core bicomponent fiber used as a crimping fiber, these fibers are widely used as bonding fibers in Nonwoven industry. The sheath of the fiber is of a lower melting point than the core and so in an elevated temperature, the sheath melts, creating bonding pints with adjacent fibers - either bicomponent or monocomponent. The first commercial

application of sheath-core binding fiber (I.C.I. Heterofil) has been in carpets and upholstery fabrics [6].

The newest trend in bicomponent fiber production is to focus on tailoring a fiber according to the customer's needs. A considerable emphasis was put on the processing optimization (depending strictly on machinery used) and on the desired look of the final product. It appears that concentricity/eccentricity of the core plays an important role. If the product strength is the major concern, concentric bicomponent fibers are used; if bulkiness is required at the expense of strength, the eccentric type of the fiber is used [11]. Other uses of sheath-core fibers derive from characteristics of the sheath helping to improve the overall fiber properties. A sheath-core fiber has been reported [7] whose sheath is made of a polymer having high absorptive power for water, thereby having obvious advantages for use in clothing. Other sheath-core fibers showed better dyeability, soil resistance, heat-insulating properties, adhesion etc. [8]. Production of ceramic sheath-core bicomponent fibers is another application utilizing the difference of sheath and core [3].

The fiber precursors are first spun in a sheath-core arrangement and then cured by oxidation, UV and electron beam, heating or by chemical means. These fibers are used as a composite reinforcement.

It is essential that the viscosities of both polymer fluids are of comparable value; otherwise, the higher viscosity component will not tend to rearrange during spinning causing the distortion of the distribution of the components in the cross section of the fiber.

Considerable attention should be also paid to the rate of solidification of each component. It has been shown that during high speed spinning of PP/PET sheath-core fibers [3] that the PET component achieved higher orientation than would be obtained if the fiber was just monocomponent, while PP component orientation was decreased [9]. This phenomenon is explained in terms of difference in activation energy of the longitudinal viscosity and solidification temperature of both polymers.

3 Exprimental part

3.1 Objections

1) Lamination of nonwoven fabric and nanofibrous layer
2) Comparing the penetration and efficiency for each sample.
3) Comparing the strength of joint for each sample.
4) Find the bending length to determine the flexural rigidity for each sample and compare them.
5) Using Tabletop SEM image find images of samples.

3.1.1 Used instruments

Diagram 8: Shows the lamination machine of nonwoven with nanofibrous layer

Lamination machine of nonwoven are double belt presses with integrated contact heating and cooling. The materials that are laminated are heated very gentle. Due to the long heating zone the materials are laminated perfectly with high bonding strength. Right after the heating the materials can be pressed together or calibrated to a set thickness with the pressure rollers. To stabilize this compound the materials a cooled down before they exit the double belt press.

Diagram 9: Shows the Sodium Chloride Filter instrument

Sodium Chloride Filter instrument is use for the calculate penetration and efficiency of each samples as well as pressure (table 1, appendix).

Diagram 10: Shows the Tensile Tester instrument

A tensile tester, also known as a tension test, tests a material's strength. It's a mechanical test where a pulling force is applied to a material from both sides until the sample changes its shape or breaks. It's is a common and important test that provides a variety of information about the material being tested, including the elongation, yield point, tensile strength, and ultimate strength of the material. Tensile tests are commonly performed on substances such as metals, plastics, wood, and ceramics.

Tensile testing systems use a number of different units of measurement. The International System of Units, or SI, recommends the use of Newtons (N) for describing tensile strength. In the United States, many engineers measure tensile strength in kilo-pound per square inch (KSI).

Diagram 10: Shows the Tabletop SEM image instrument

Tabletop SEM image was used to find images for samples

3.2 Analytical procedure

3.2.1 Prepared types of sample

The lamination machine was used to prepare following types of samples:

Sample 1:NF 0,1 $g.m^{-2}$+ SB 18 $g.m^{-2}$

Sample 2:NF 0,05 $g.m^{-2}$ + SB 18 $g.m^{-2}$

Sample 3:SB 12 $g.m^{-2}$+ NF 0,1 $g.m^{-2}$+ SB 18 $g.m^{-2}$

Sample 3:SB 12 $g.m^{-2}$+NF 0,05 $g.m^{-2}$+SB 18 $g.m^{-2}$

Sample 4:SB 12 $g.m^{-2}$+NF 0, $g.m^{-2}$+SB 18 $g.m^{-2}$+NF 0,1 $g.m^{-2}$+SB 18 $g.m^{-2}$

Sample 4:SB 12 $g.m^{-2}$+NF 0,05 $g.m^{-2}$+SB 18 $g.m^{-2}$+NF 0,05 $g.m^{-2}$+SB 18 $g.m^{-2}$

3.2.2 Conditions that were used for each samples

Temperature: 120 ° C, 130 ° C and 140 ° C.

Pressures: 0, 0.5, 1, 1.5 $kg.m^{-2}$

Rate of passage: 1.3 m / min

3.3 Experiments and procedure

3.3.1 Material used

Bicomponent nonwoven fabric made of technology spunbond which include polyethylene and polypropylene. The nanofibrous layer, PAN was use to bind the two fibers. These two materials were laminated through laminating machine at different temperature as well as pressure. Polyethylene coat individual filaments (filaments) gives the resulting nonwoven fabric very specific properties that are characterized by very soft and pleasant feel, excellent, comfortable properties upon contact with human skin sections, higher elasticity.

The following tables are shown for clarity individual samples and the conditions for bonding

Table 1: Shows sample 1 in details and the bonding was NF 0.1 g/m2 + SB 18 g/m^2

Sample 1 no.	Temperature [°C]	Pressure[$kg.m^{-2}$]
A	130	0
B	130	0,5
C	130	1
D	130	1,5
E	120	1,5
F	120	1
G	120	0,5
H	120	0

Table 2: Shows sample 2 in details and the bonding was NF 0.05 g/m^2 + SB 18 g/m^2

Sample 2 no.	Temperature [°C]	Pressure[$kg.m^{-2}$]
A´	140	0
B´	140	0,5
C´	140	1
D´	140	1,5
E´	130	1,5
F´	130	1
G´	130	0,5
H´	130	0

Table 3: Shows sample 3 in details and the bonding was SB 12$g.m^{-2}$ + NF 0,1$g.m^{-2}$ + SB 18$g.m^{-2}$

Sample3 no.	Temperature [°C]	Pressure[$kg.m^{-2}$]
A´´	130	0
B´´	130	0,5
C´´	130	1
D´´	130	1,5

Table 4: Shows sample 3 in details and the bonding was SB 12g/m^2+ NF 0,05g/m^2+ SB 18g/m^2

Sample 3 no.	Temperature [°C]	Pressure kg/m2
E´´	130	1,5
F´´	130	1
G´´	130	0,5
H´´	130	0

Table 5: Shows sample 4 in details and the bonding was SB 12g/m^2+NF 0,1g/m^2+SB 18 g/m^2 + NF 0,1g/m2+SB 18 g/m^2

Sample 4 no.	Temperatue [°C]	Pressure[kg/m^2]
1	130	0
2	130	0,5
3	130	1
4	130	1,5
5	120	1,5
6	120	1
7	120	0,5
8	120	0

Table 6: Shows sample 4 in details and the bonding was SB 12g/m^2+NF 0,05g/m^2+SB 18 g/m^2+NF 0,05g/m^2+SB 18 g/m^2

Sample 4 no.	Temperature[°C]	Pressure [kg/m^2]
9	120	0
10	120	0,5
11	120	1
12	120	1,5
13	130	1,5
14	130	1
15	130	0,5
16	130	0

3.3.2 The used of Sodium Chloride Filter instrument

Sodium Chloride Filter instrument was use for the calculate penetration and efficiency (see appendix, table 20) of each samples as well as pressure measuring the effectiveness of detection and pressure drop of single samples.

Measuring parameters: NaCl aerosol

Particle velocity = 5 m / min

Particle size from 0.2 microns to 2 microns

Table 7: Shows the efficiency and pressure of sample 1 from sodium chloride filter instrument.

Sample 1	Efficiency [%]	Pressure[Pa]
A	93,23	68
B	95,52	85
C	94,34	97
D	93,44	95
E	93,51	93
F	93,42	91
G	90,32	78
H	94,07	70

Sample without bonding shows the efficiency of 96.7 % and Pressure of 62 Pa

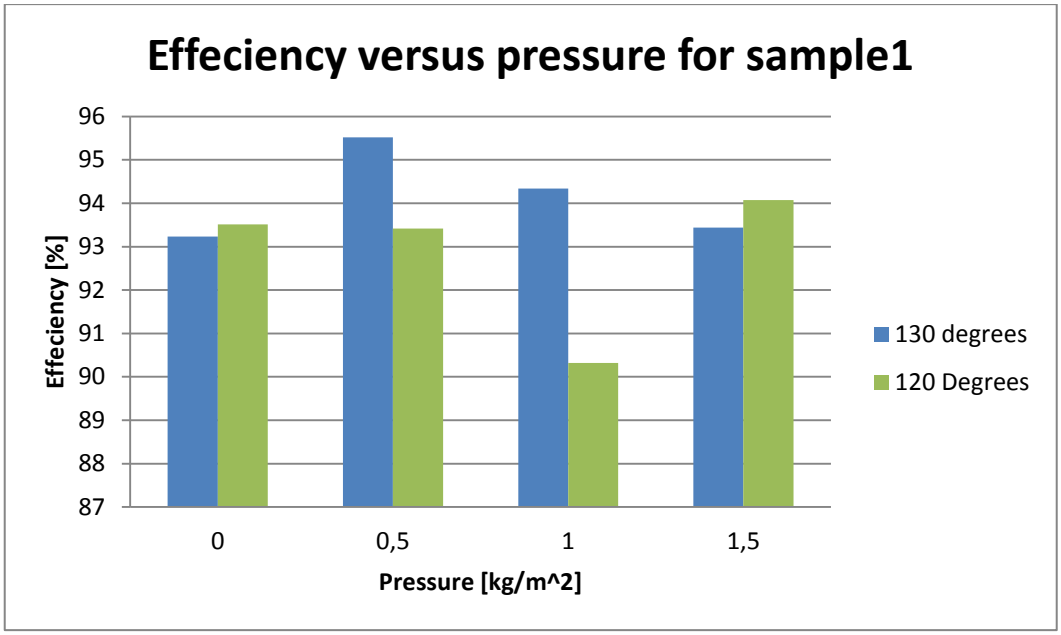


Figure 1.Shows the efficiency as well as pressure for sample number A to H.

Table 8: Shows the efficiency and pressure of sample 2 from sodium chloride filter instrument.

Sample 2	Efficiency [%]	Pressure[Pa]
A´	27,64	23
B´	34,42	24
C´	32,21	28
D´	34,01	30
E´	35,51	32
F´	33,42	31
G´	32,01	26
H´	34,8	17

Sample without bonding shows the efficiency of 36.7 % and Pressure of 15 Pa.

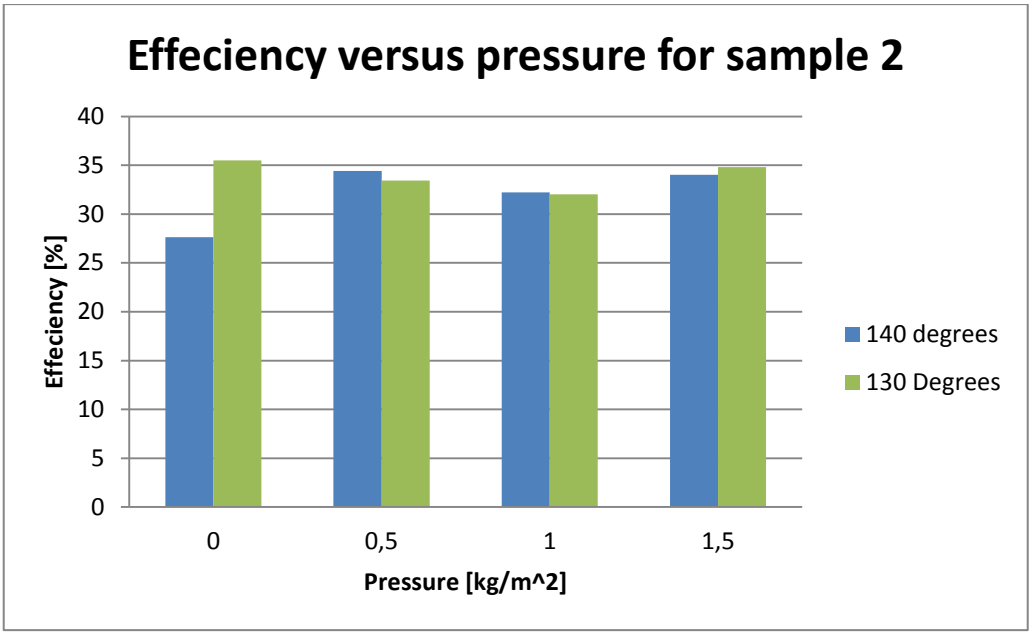


Figure 2. Shows the efficiency as well as pressure for sample number A´ to H´.

Table 9: Shows the efficiency and pressure of sample 3 from sodium chloride filter instrument

Sample 3	Efficiency [%]	Pressure[Pa]
A´´	94,71	94,00
B´´	94,03	113,50
C´´	94,54	166,00
D´´	93,42	175,50

Sample without bonding shows the efficiency of 97.55 % and Pressure of 82 Pa

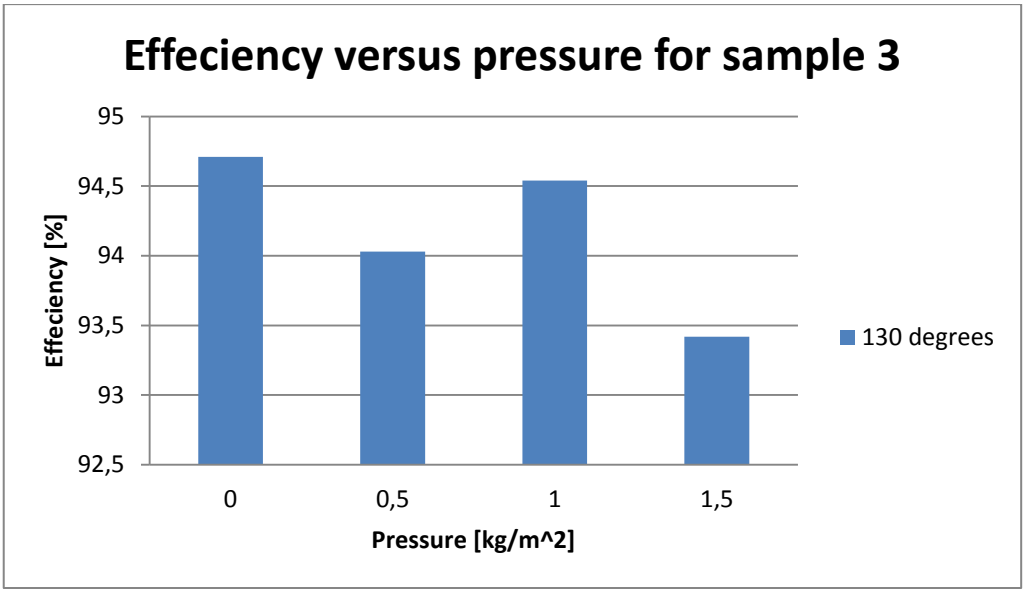


Figure 3. Shows the efficiency as well as pressure for sample number A´´ to D´´

Table 10: Shows the efficiency and pressure of sample 3 from sodium chloride filter instrument

Sample 3	Efficiency [%]	Pressure[Pa]
E´´	71,40	76,00
F´´	70,70	61,00
G´´	70,90	54,00
H´´	68,50	36,00

Sample without bonding shows the efficiency of 80.22 % and Pressure of 32 Pa

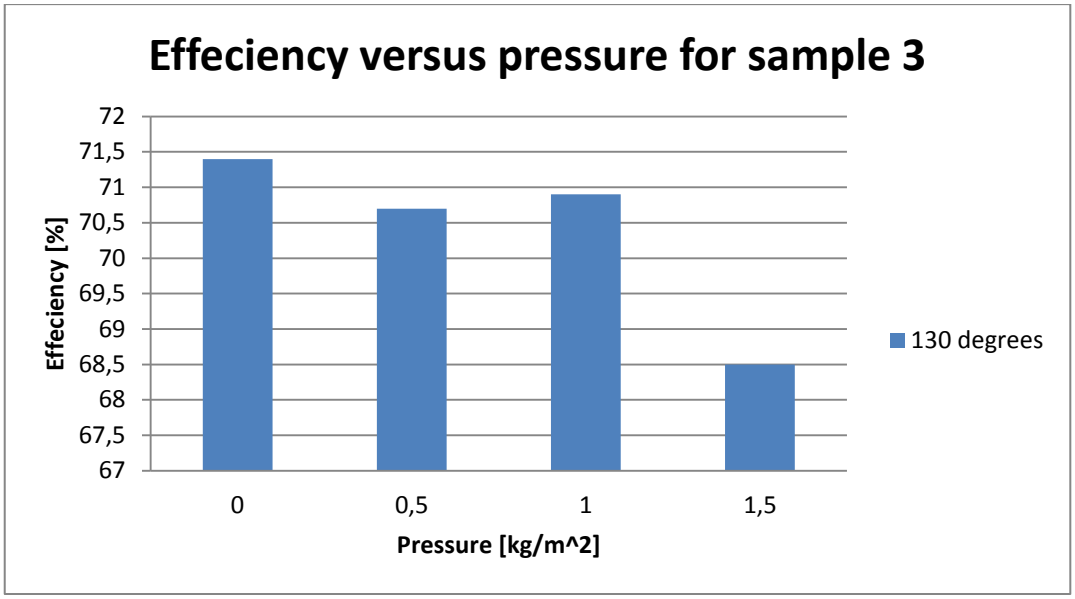


Figure 4. Shows the efficiency as well as pressure for sample number E´´to H´´

Table 11: Shows the efficiency and pressure of sample 4 from sodium chloride filter instrument

Sample 3	Efficiency [%]	Pressure[Pa]
1	93,36	115
2	93,02	157,00
3	93,52	155,00
4	92,63	171,00
5	93,79	95,00
6	94,95	116,00
7	95,36	86,00
8	94,77	65,00

Sample without bonding shows the efficiency of 95.53 % and Pressure of 65 Pa

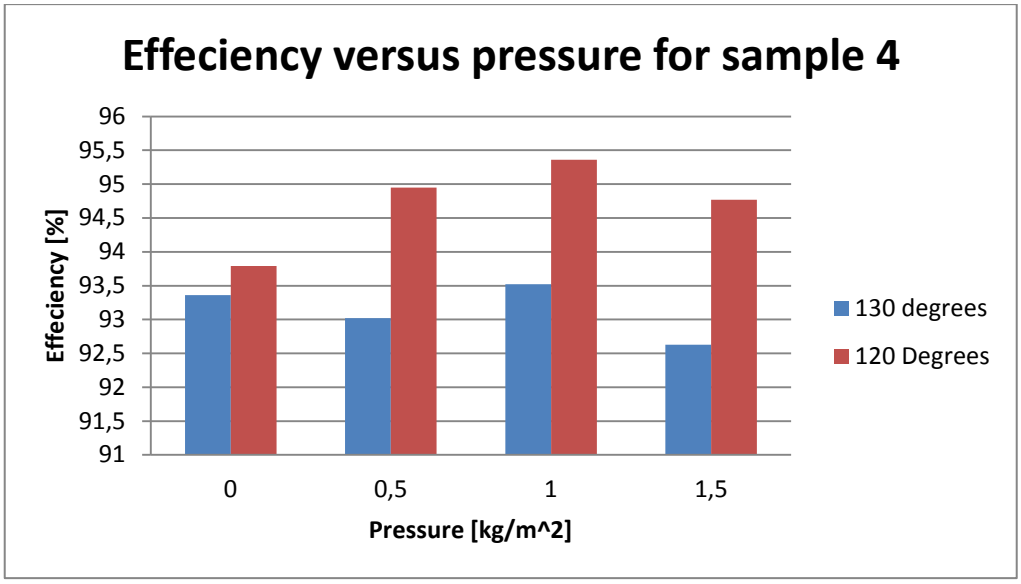


Figure 5. Shows the efficiency as well as pressure for sample number 1 to 8.

Table 12: Shows the efficiency and pressure of sample 4 from sodium chloride filter instrument

Sample 3	Efficiency [%]	Pressure[Pa]
9	95,51	67,00
10	93,75	67,00
11	93,41	120,00
12	92,61	92,00
13	88,90	141,00
14	88,50	130,00
15	88,53	107,00
16	89,70	68,00

Sample without bonding shows the efficiency of 96.12 % and Pressure of 66 Pa

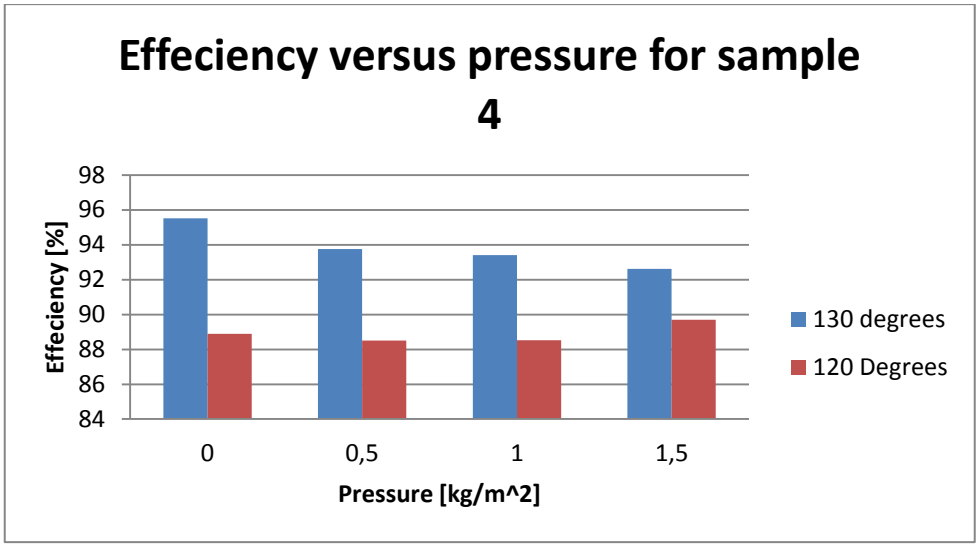


Figure 6 Shows the efficiency as well as pressure for sample number 9 to 16.

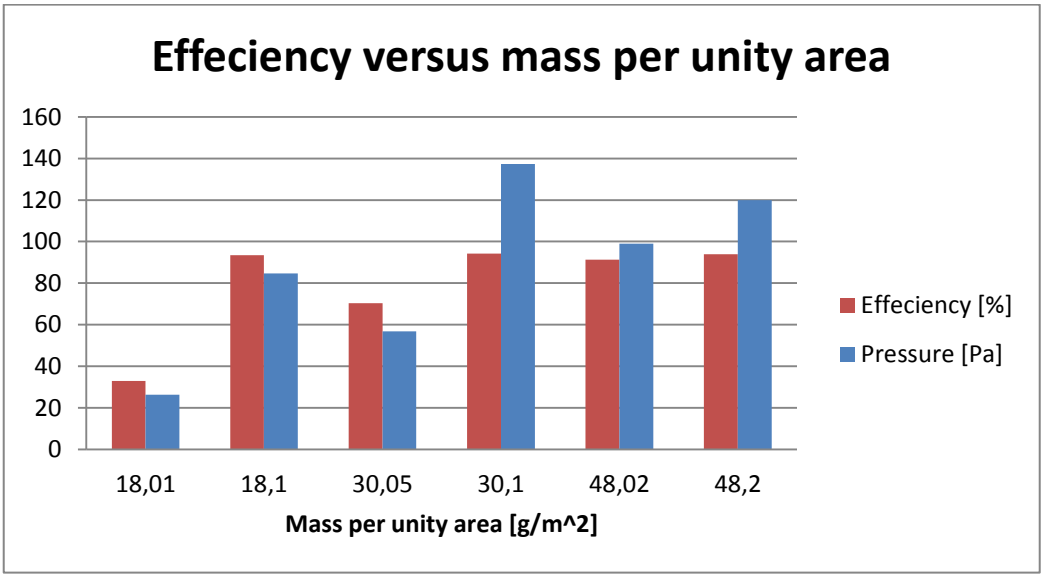


Figure 7 Shows the average efficiency and pressure for each sample number with mass per unity area.

3.3.3 Discussion of efficiency and pressure results

Sample 1 was analyzed using table 7 and figure 1. Sample 1 in details and the bonding was NF 0.1 g/m^2 + SB 18 g/m^2. Table 7 shows sample 1 with a slightly decrease in efficiency after bonding. However, the efficiency decrease further as the machine pressure increases and machine temperature decrease (see figure 1).On the other hand, the pressure drop is also directly proportional to machine pressure (see table 7).

Sample 2 was analyzed using table 8 and figure 2. The sample details and the bonding was NF 0.05 g/m^2 + SB 18 g/m^2.Pressure drop and machine pressure when the samples' temperature is 140 ^{0}C is directly proportional to each other while on the other hand the efficiency after bonding is far less then sample 1.The efficiency after bonding is inversely proportional to machine pressure when decrease the temperature to 130 ^{0}C (see table 8 and figure 2).

Table 9 for samples SB 12g.m^{-2} + NF 0,1g.m^{-2} + SB 18g.m^{-2} again shows deterioration in efficiency and pressure drop samples after bonding.

Table 10 for samples SB 12g/m^2+ NF 0,05g/m^2+ SB 18g/m^2 shows the same trend as the previous table**.**

The machine temperature for sample 3 was the same.

The composition of samples, table 11 is SB 12g/m^2+NF 0,1g/m^2+SB 18g/m^2 + NF 0,1g/m2+SB 18 g/m^2. Table 11 shows the best samples No. 6 and No. 7, the samples bonded at temperature of 120 ° C and pressures of 0.5 and 1 kg/m^2, consecutively.

The composition of samples, table 12 is SB 12g/m^2+NF 0,05g/m^2+SB 18 g/m^2+NF 0,05g/m^2+SB 18 g/m^2 is the same trend however low drop pressure and temperature of 120 ° C.

The mostly significant notice for these samples is that when the samples have a more mass per unity area, that samples have more efficiency as well as pressure (figure 7).

3.3.4 Testing of bond strength by using Tensile Tester instrument

Tests were conducted with sample 3 and the bonding in details was SB 12g.m^{-2} + NF 0,1g.m^{-2} + SB 18g.m^{-2} ,(A"- D´´); SB 12g/m^2+ NF 0,05g/m^2+ SB 18g/m^2 (E´´ -H") and sample 4 and the bonding in details was SB 12g/m^2+NF 0,1g/m^2+SB 18 g/m^2 + NF 0,1g/m2+SB 18 g/m^2 ,(1-8); SB 12g/m^2+NF 0,05g/m^2+SB 18 g/m^2+NF 0,05g/m^2+SB 18 g/m^2 ,(9-16).

For sample 1, A-H and sample 2, A'-H' due to the higher bond strength than the strength of individual layers of the bond strength was not measured. Strength of nanofiber layer is virtually immeasurable.

The results are shown in the tables below and measurement were done according Tensile Tester instrument – which measured bond strength (see appendix, table 24 and table 25).

Table 13: Shows the average measured bond strength of sample 3 according Tensile Tester instrument.

Sample no.	Force[N]
A´´	3.11
B´´	3.93
C´´	2.43
D´´	3,05
E´´	1.18
F´´	2.35
G´´	0.513
H´´	5.94

Table 14: Shows the measured bond strength of sample 4 according Tensile Tester instrument.

Sample no.	Force [N]
1	0
2	1.69
3	3.16
4	1.58
5	0
6	0
7	0
8	0
9	0
10	2.72
11	3.02
12	2.77
13	3.69
14	1.45
15	1.93
16	2.30

For comparison, SB-bond strength of materials without NF bonded under conditions of 130 ° and zero pressure is 2.14 N (see appendix table 5).

3.3.5 Discussion of bond strength results

Sample number 5 to 9 were bonded at 120°C and show no bond strength, there was no connection. The results show no trends, such as that with the increasing pressure of growing strength. The measured strength values in different places often fluctuate, which can be explained by the irregularity of the SB material.

It is obvious that the temperature is crucial. It appears from samples (A"-H") with a bonding conditions of 130 ° C and pressures of 0.5 kg/m^2, practically. However, between samples number A' to H" there is no noticeable trend. For composite samples number 1 to 16 the best bonding conditions temperature is 130 °C and pressure of 1 kg/m^2 for SB 12g/m^2+NF 0,1g/m^2+SB 18 g/m^2 + NF 0,1g/m2+SB 18 g/m^2 bonding details and also 0 kg/m^2 for SB 12g/m^2+NF 0,05g/m^2+SB 18 g/m^2+NF 0,05g/m^2+SB 18 g/m^2 bonding details.

3.3.6 The flexural rigidity of the material after bonding

The stiffness of the sample was measured according to Edana ERT 50.5 (99). The fully results are shown in appendix table 26 to 29.

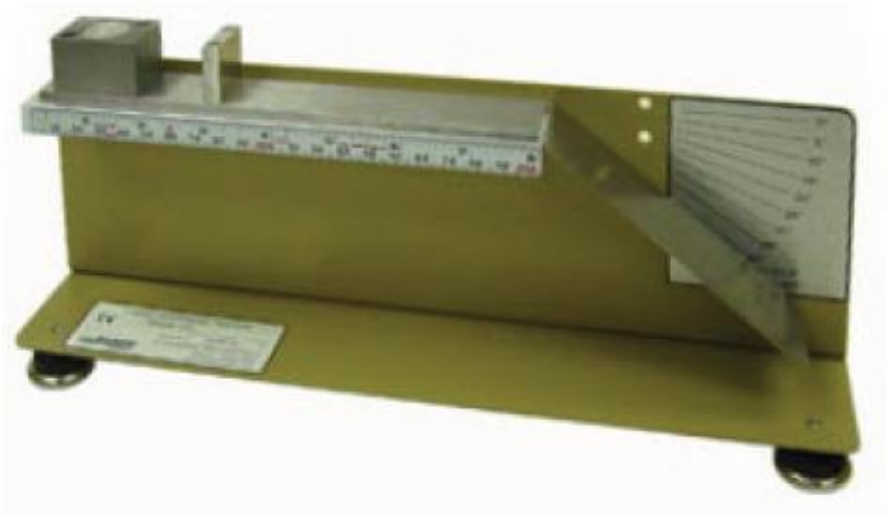


Diagram 11 shows the modem of calculating the flexural rigidity

$$G = 0.1 \times W\ [g/m^2] \times C^3[m] \times 1000\ [8]$$

Table 15: Shows the measured stiffness of the material after bonding of sample 1

	MD	CD	G[mgm]MD	G[mgm]CD
A	4.25	2.40	1.39	0.25
B	7.00	3.13	6.21	0.55
C	6.13	2.75	4.16	0.38
D	6.85	3.23	5.82	0.61
E	6.13	2.88	4.16	0.43
F	6.25	3.08	4.42	0.53
G	6.75	3.13	5.57	0.55
H	6.45	3.10	4.86	0.54

$$W = 18.10\ g/m^2$$

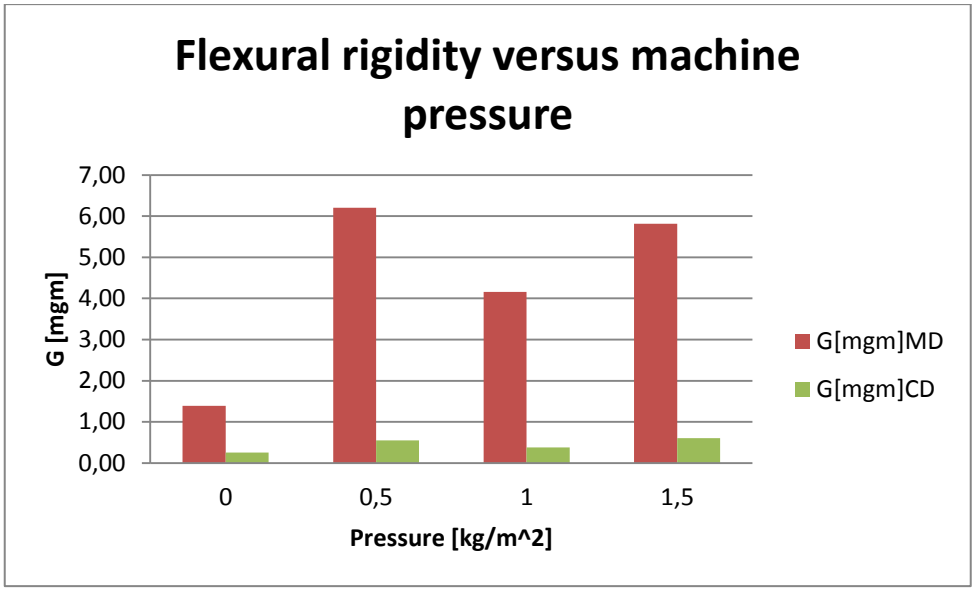


Figure 8.Shows the flexural rigidity versus machine pressure for sample number A to D.

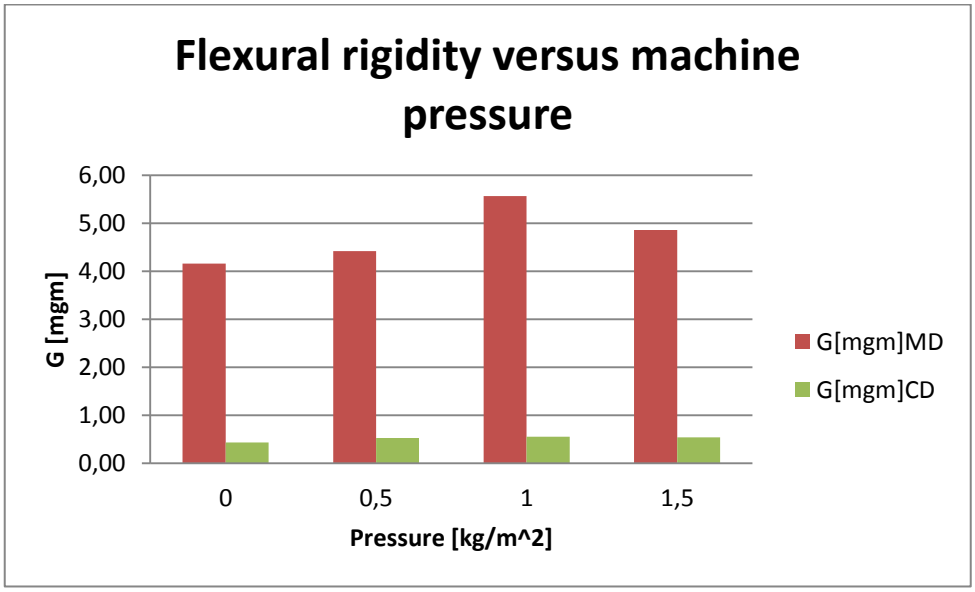


Figure 9. Shows the flexural rigidity versus machine pressure for sample number E to H.

Table 16: Shows the measured stiffness of the material after bonding of sample 2

	MD	CD	G[mgm]MD	G[mgm]CD
A'	7.20	4.03	6.72	1.17
B'	6.00	4.00	3.89	1.15
C'	5.30	3.43	2.68	0.72
D'	6.78	3.80	5.60	0.99
E'	7.15	3.75	6.58	0.95
F'	5.83	4.20	3.56	1.33
G'	7.18	4.00	6.65	1.15
H'	6.95	3.70	6.05	0.91

W =18.01 g/m^2

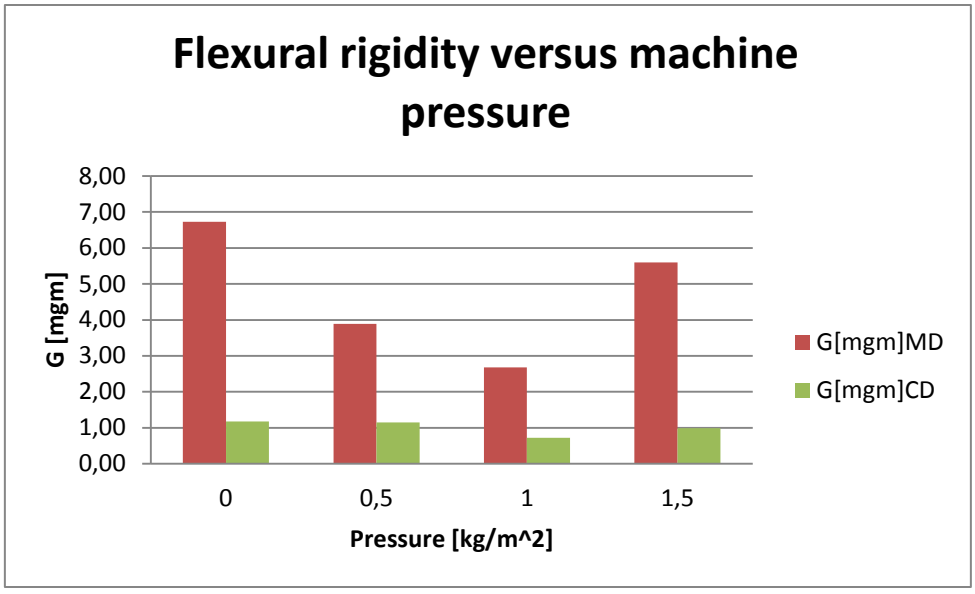


Figure 10. Shows the flexural rigidity versus machine pressure for sample number A' to D'.

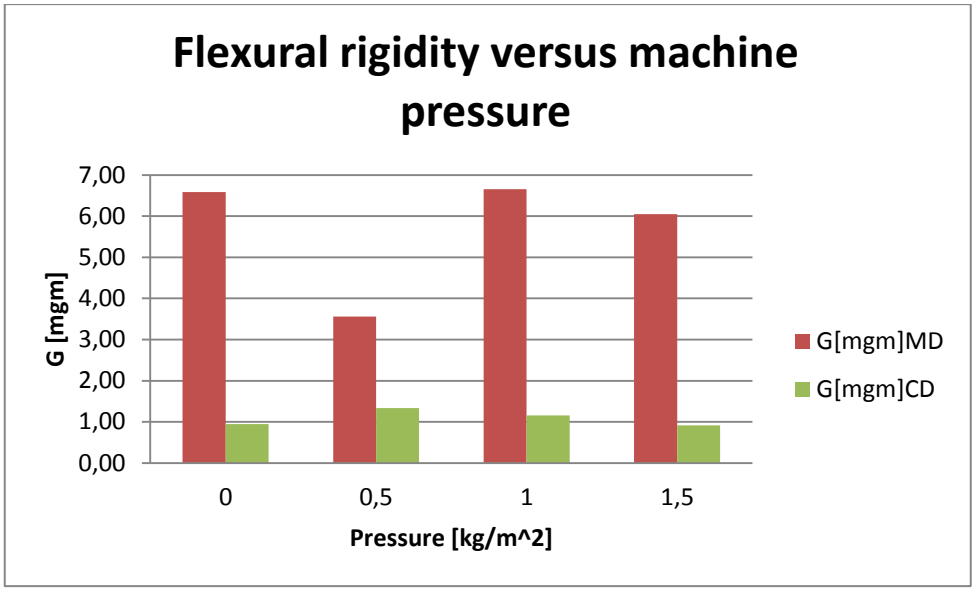


Figure 11. Shows the flexural rigidity versus machine pressure for sample number E' to H'

Table 17: Shows the measured stiffness of the material after bonding of sample 3

	MD	CD	G[mgm]MD	G[mgm]CD
A"	8.98	5.75	21.76	5.72
B"	7.83	6.35	14.42	7.71
C"	9.25	6.90	23.82	9.89
D"	8.38	5.85	17.68	6.03
E"	8.00	5.25	15.39	4.35
F"	8.38	5.88	17.65	6.09
G"	10.53	6.70	35.04	9.04
H"	11.10	6.58	41.10	8.54

W=30.1 g/m^2 sample number A" to D" and W=30.05 g/m^2 for sample number E" to H".

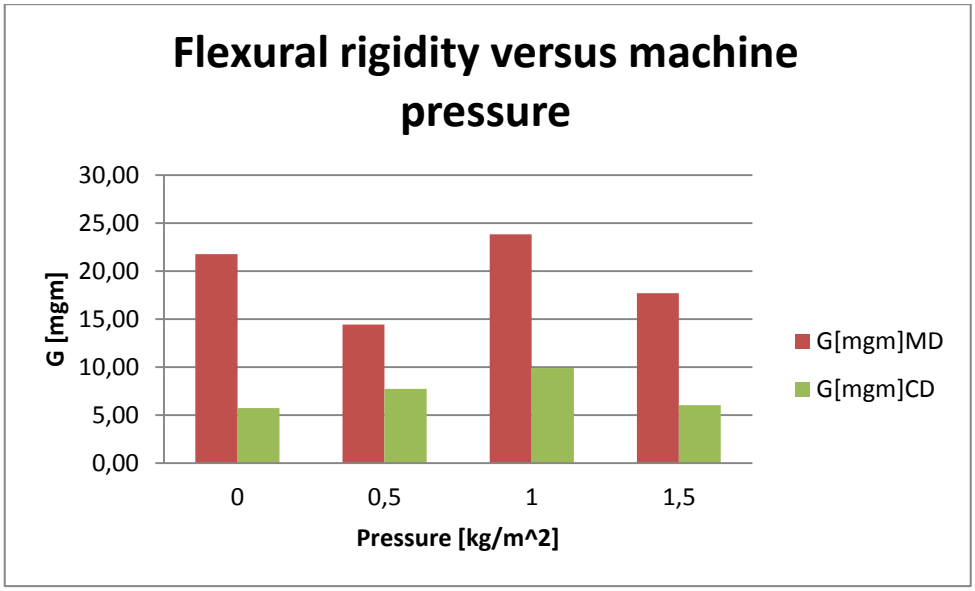


Figure 12. Shows the flexural rigidity versus machine pressure for sample number A'' to D''

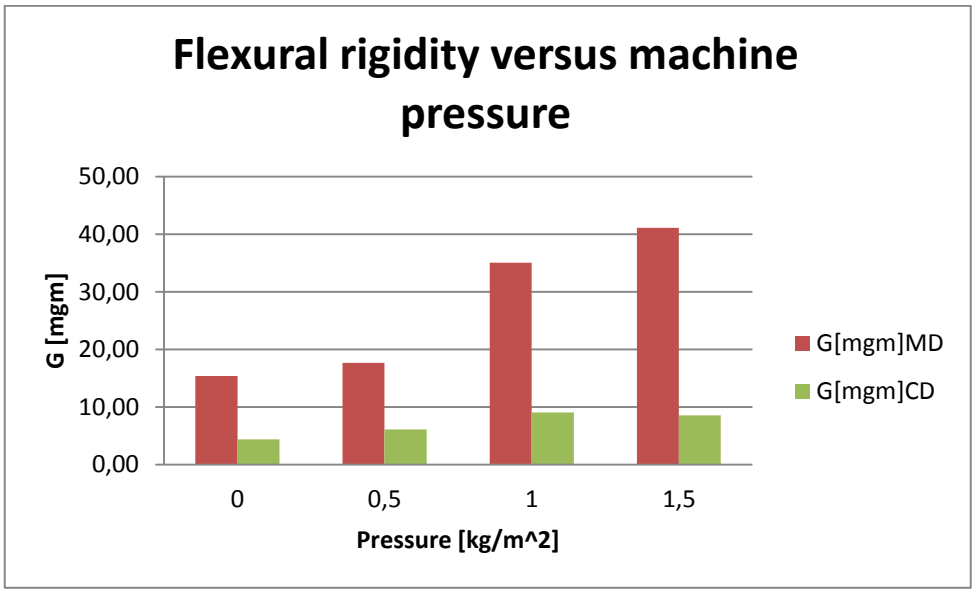


Figure 13. Shows the flexural rigidity versus machine pressure for sample number E'' to H''

Table 18: Shows the measured stiffness of the material after bonding of sample 4

	MD	CD	G[mgm]MD	G[mgm]CD
1	0.00	0.00	0.00	0.00
2	9.40	8.23	40.03	26.82
3	9.50	7.83	41.33	23.09
4	11.03	8.03	64.59	24.91
5	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00

W =48.20 g/m^2

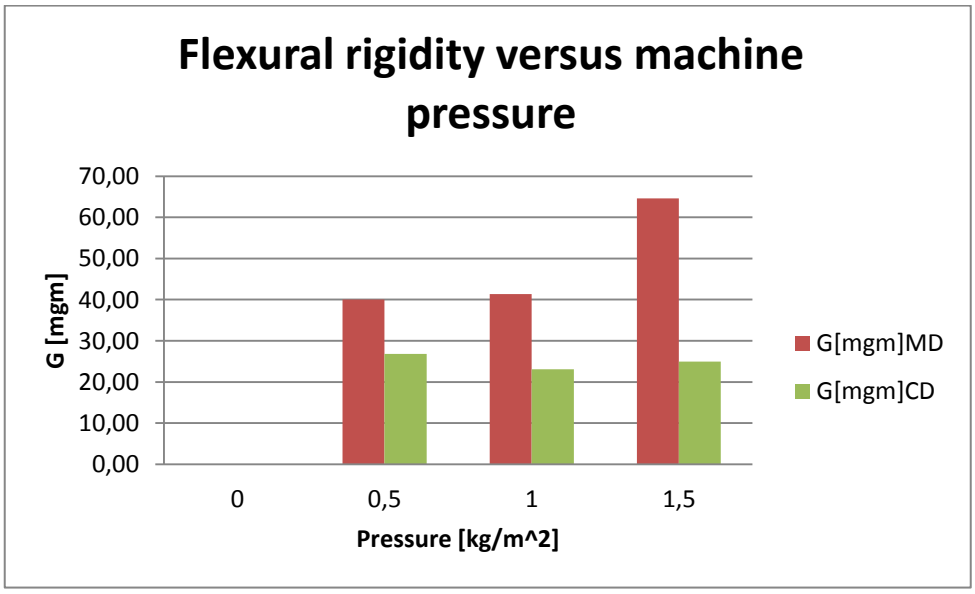


Figure 14. Shows the flexural rigidity versus machine pressure for sample number 1 to 4.

Table 19: Shows the measured stiffness of the material after bonding of sample 4

	MD	CD	G[mgm]MD	G[mgm]CD
9	0.00	0.00	0.00	0.00
10	10.18	4.53	50.59	4.45
11	10.60	4.20	57.19	3.56
12	6.58	4.28	13.65	3.75
13	10.18	8.93	50.59	34.14
14	13.58	8.45	120.13	28.97
15	14.30	7.45	140.42	19.86
16	11.55	8.75	73.99	32.17

W =48.10 g/m^2

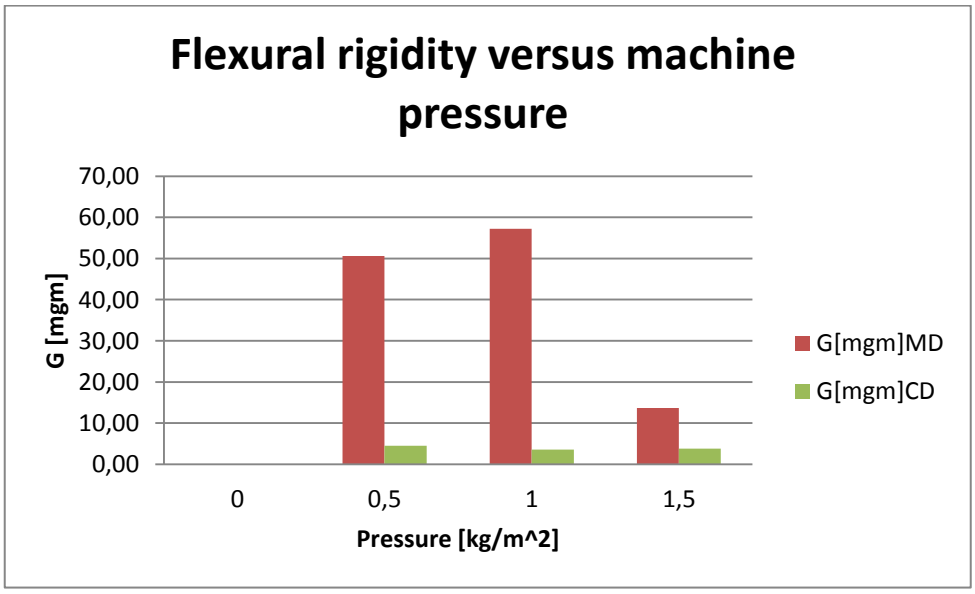


Figure 15. Shows the flexural rigidity versus machine pressure for sample number 9 to 12.

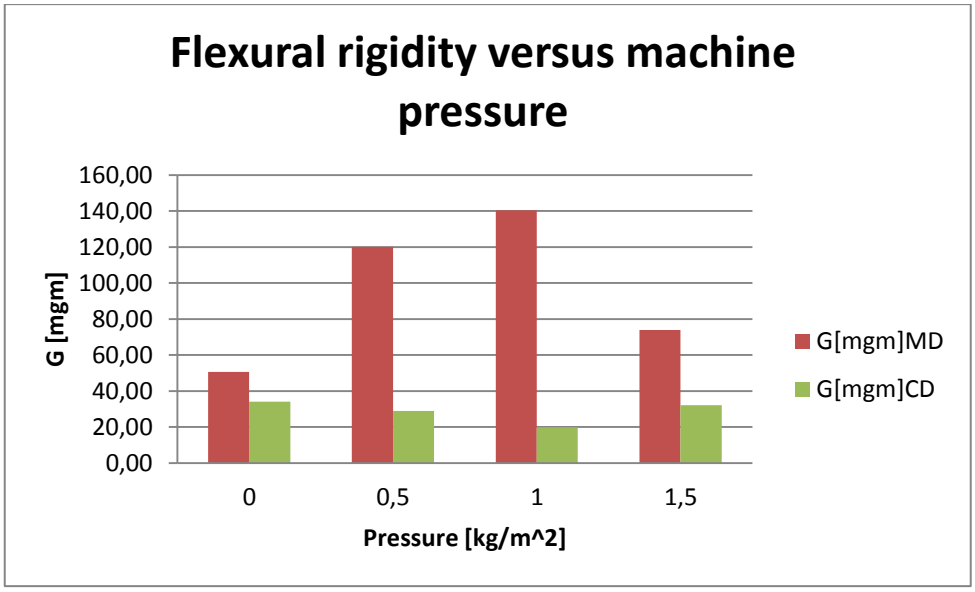


Figure 16.Shows the flexural rigidity versus machine pressure for sample number 13 to 16.

The stiffness of the sample without nanofiber layer and single layer under SB 130 °C and the bonding pressure is zero for flexural rigidity (MD) = 1.35 (practically the same as sample A) and flexural rigidity (CD) = 1,32.

Stiffness of the sample measured under the same conditions described above material SB 12g/m^2 SB 18g/m2 g/m^2 , flexural rigidity (MD) = 12.5 and flexural rigidity (CD) = 4.25.

Material composition SB 12g/m^2 + SB 18 g/m^2 + SB18 g/m^2 flexural rigidity (MD) = 42.35 and flexural rigidity (CD) = 22.83.

3.3.7 Discussion of flexural rigidity of the material results

Individual groups of samples should be evaluated separately due to different weight. For sample number A to H can be read from the table 15 , figure 8 and figure 9. It can be noticeable that in the longitudinal direction, the is an increased of stiffness for a temperature of 130°C with increasing bonding pressure and it a big jumps between samples A and B. In addition, it is the rigidity of the samples for the same temperature. The same applies to the transverse direction. In addition to that figure 8 and figure 9 shows it clear that longitudinal machine has more stiffness compares to transverse direction. Figure 8 is sample number A to D with 130 ^{0}C and figure 9 is sample number E to F with 120 ^{0}C.

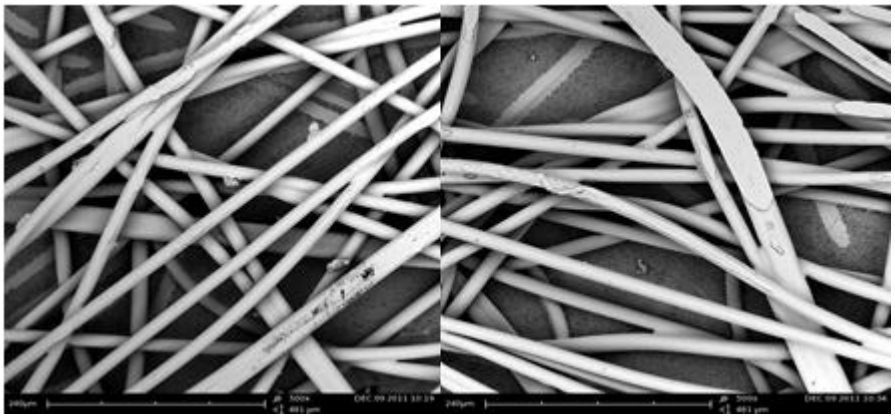
Sample number A' to H', table 16 shows it clear that bonding increases the stiffness of the samples (see figure10 and 11), but virtually impossible to write about any dependencies on increasing the pressure or temperature change, which is rather the spun bond material, irregularity.

For sample number A" to H", table 17 bonding increases the stiffness. The stiffness of specimens with sample number A to H compared with materials sample number A' to H' which is increased due to their composition. This is more evident in the longitudinal direction as well as transverse direction (see figure 12 and 13).

Multilayer sample number 1 to 16 shows a greater increase in flexural rigidity /stiffness logically than previous samples. Materials marked with zero in the table 18 and 19 have not been measured because of an unrelated.

The presence of NF does not affect the stiffness of the material bonding see virtually no effect. These values for materials without the NF are listed below the figure 16.

3.3.8 The images of some samples by SEM instrument.



This images were taken at the magnification of 500x. What can be noted the most about it is that nanofibrous, PAN bind to bicomponent very well for some sample numbers (see appendix for more images).

4 Conclusion

Variety materials for bonding were created following lamination (see 3.2.1) and two tests were conducted which included the SEM analysis for some materials (see appendix).The aim was to find suitable conditions for bonding so that the material exhibited the best properties. For materials A-H and A'-H ' the best be assessed in terms of capture efficiency and pressure drop. The sample number B and B' is bonded at 130 ° and a pressure of 0.5 kg/m^2. For these samples was the condition and connection of NF and SB. Furthermore, in terms of stiffness, the two samples show elevated levels mainly in the longitudinal direction sample number B, but the increase is not dramatic.

The best of materials A"-D" appears to be in terms of efficiency properties. The sample number A" is 130 ° at zero pressure. The bond strength is sufficient for this sample. The stiffness of the sample shows a slight increase in the longitudinal direction and in the transverse direction contrary does not deviate with an average value. For materials marked E"- H". The scales for comparison of efficiency and pressure drop say that the best was sample number E" . Conditions for sample number E" bonding were 130 ° and 1.5 kg/m^2. The bond strength is high.

Materials samples that were labeled 1-16, multilayer samples. After evaluating the results we can exclude samples 1 and 5-9 from the evaluation since their unconnected. Although showing good filtration properties thus high detection efficiency and low pressure drop, but the above reasons, the materials cannot be used. Materials number 2 and 3 are virtually identical in terms of efficiency and pressure drop, material designated. Materials conditions were 130°C at the pressure of 0.5 and 1 kg/m^2, consecutively. What can be noted the most about this multilayer samples was that the bond strength and stiffness were doubled compared to other types of materials. The material marked 10-16, in terms of filter characteristics appears to be best material designated. For example sample number 10 had a temperature of 120 °C and 0.5 kg/m^2. The bond strength is sufficient and the sample does not deviate or stiffness in the longitudinal or transverse direction.

SEM analysis was used to show how that lamination works and also how this fibers were bonded. For future work, some lamination such as material sample 1 and 5-9, were unfortunately unsuccessful; therefore future studies should be directed towards the development of new methods. Expansion of the existing methods is also necessary in order to produce a wide variety of this kind of Bicomponent fibers. The other study should focus on the, SEM analysis, where images will me use for calculating area covered by fibers without pores.

5 References:

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6 Appendix

Table 20: Shows the calculated penetration and efficiency for sample 1.

Sample No.	Temperature [^{0}C]	Pressure [Pa]	Penetration [%]	Efficiency [%]	Velocity [m/min]
A	130	68	6.77	93.23	5.00
B	130	85	4.48	95.52	5.00
C	130	97	5.66	94.34	5.00
D	130	95	6.56	93.44	5.00
E	120	93	6.49	93.51	5.00
F	120	91	6.58	93.42	5.00
G	120	78	9.68	90.32	5.00
H	120	70	5.93	94.07	5.00

Table 21: Shows the calculated penetration and efficiency for sample 2.

Sample No.	Temperature [^{0}C]	Pressure [Pa]	Penetration [%]	Efficiency [%]	Velocity [m/min]
A'	140	23	72.36	27.64	5.00
B'	140	24	65.58	34.42	5.00
C'	140	28	67.79	32.21	5.00
D'	140	30	65.99	34.01	5.00
E'	130	32	64.49	35.51	5.00
F'	130	31	66.58	33.42	5.00
G'	130	26	67.99	32.01	5.00
H'	130	17	65.2	34.80	5.00

Table 22: Shows the calculated penetration and efficiency for sample 3

Sample No.	Temperature [^{0}C]	Pressure [Pa]	Penetration [%]	Efficiency [%]	Velocity [m/min]
A"	130	94,00	5.29	94,71	5.00
B"	130	113,50	5.97	94,03	5.00
C"	130	166,00	5.46	94,54	5.00
D"	130	175,50	6.58	93,42	5.00
E"	130	76,00	28.60	71,40	5.00
F"	130	61,00	29.30	70,70	5.00
G"	130	54,00	29.10	70,90	5.00
H"	130	36,00	31.50	68,50	5.00

Table 23: Shows the calculated penetration and efficiency for sample 4

Sample No.	Temperature [^{0}C]	Pressure [Pa]	Penetration [%]	Efficiency [%]	Velocity [m/min]
1	130	115	6.64	93,36	5.00
2	130	157,00	6.98	93,02	5.00
3	130	155,00	6.48	93,52	5.00
4	130	171,00	7.37	92,63	5.00
5	120	95,00	6.21	93,79	5.00
6	120	116,00	5.05	94,95	5.00
7	120	86,00	4.64	95,36	5.00
8	120	65,00	5.23	94,77	5.00
9	120	67,00	4.49	95,51	5.00
10	120	67,00	6.25	93,75	5.00
11	120	120,00	6.59	93,41	5.00
12	120	92,00	7.39	92,61	5.00
13	130	141,00	11.1	88,90	5.00
14	130	130,00	11.5	88,50	5.00
15	130	107,00	11.47	88,53	5.00
16	130	68,00	10.3	89,70	5.00

Table 24: Shows the result measured for strength of sample 3.

Sample No.	Fb	Amax	Ab	Fmax
	N	mm	mm	N
A"	1.69	7.33	69.95	2.35
A"	2.89	36.07	69.93	3.36
A"	3.23	65.43	69.94	3.61
Average				**3.11**
B"	3.67	66.62	69.95	4.11
B"	3.01	34.96	69.96	4.86
B"	2.01	54.11	69.93	2.82
Average				**3.93**
C"	1.73	59.04	69.95	2.35
C"	1.95	68.96	69.94	2.13
C"	2.6	63.25	69.93	2.82
C"	1.82	37.74	69.94	2.42
Average				**2.43**
D"	2.7	17.06	69.93	3.14
D"	2.32	20.77	69.96	2.89
D"	2.35	56.27	69.96	3.11
Average				**3.0467**
E"	1.1	33.38	69.93	1.25
E"	1.07	1.12	69.95	1.1
E"	1	1.1	69.96	1.1
E"	0.94	13.38	69.96	1.25
Average				**1.175**
F"	1.79	61.15	69.94	2.2
F"	1.88	33.91	69.95	2.82
F"	0.97	32.17	69.94	2.04
Average				**2.353**
G"	0.47	18.27	69.93	0.63
G"	0.47	19.1	69.93	0.63
G"	0.31	6.17	69.96	0.44
G"	0.31	41.74	69.96	0.35
Average				**0.513**
H"	5.68	69.73	69.95	6.05
H"	7.03	69.38	69.96	7.06
H"	3.45	61.5	69.96	4.71
Average				**5.94**

Table 25: Shows the result measured for strength of sample 4.

Sample No.	Fb	Amax	Ab	Fmax
	N	mm	mm	N
2	1.41	10.47	69.93	1.57
2	1.44	5.29	69.93	1.6
2	1.41	47	69.96	1.69
2	1.41	45.1	69.96	1.66
2	1.57	4.22	69.96	1.73
2	1.66	0.85	69.96	1.88
2	1.51	61.09	69.96	1.69
2	1.35	11.81	69.95	1.69
Average				**1.69**
3	2.98	2.97	69.96	3.8
3	2.51	34.54	69.94	3.14
3	2.64	15.48	69.93	3.45
3	3.11	15.5	69.93	3.33
3	1.04	7.86	69.93	2.07
Average				**3.16**
4	0.31	43.65	69.95	1.29
4	0.13	34.28	69.93	0.47
4	0.78	66.74	69.94	1.16
4	2.35	61.92	69.93	2.67
4	1.63	4.12	69.93	3.55
4	2.2	57.27	69.97	2.98
Average				**2.02**
10	1.6	46.19	69.93	2.04
10	2.01	47.15	69.95	2.2
10	2.73	67.86	69.95	3.17
10	2.04	5.64	69.93	2.57
10	3.07	59.74	69.94	3.58
10	2.98	69.04	69.96	3.14
10	1.41	19.18	69.95	2.2
10	2.76	69.09	69.95	2.82
Average				**2.72**

Table 26: Shows the result measured for strength of sample 4

Sample No.	Fb	Amax	Ab	Fmax
	N	mm	mm	N
11	2.92	68.9	69.94	3.14
11	2.45	7.98	69.96	2.98
11	2.79	43.4	69.96	3.14
11	2.82	65.12	69.96	2.98
11	2.67	12.44	69.94	3.2
11	2.32	64.91	69.96	2.51
11	2.6	63.35	69.94	2.85
11	2.98	64.68	69.96	3.39
Average				**3.02**
12	2.51	5.16	69.96	2.89
12	2.64	66.84	69.95	2.76
12	2.51	19.47	69.95	2.67
12	2.82	2.42	69.95	2.82
12	2.64	18.2	69.95	2.98
Average				**2.82**
13	3.23	68.74	69.93	3.45
13	3.92	69.46	69.96	4.08
13	2.67	24.6	69.96	3.29
13	3.2	33.89	69.96	3.61
13	2.89	20	69.95	3.45
13	3.8	42.45	69.93	4.24
Average				**3.69**
14	1.16	0.98	69.93	1.25
14	1.19	0.73	69.94	1.25
14	1.1	0.38	69.93	1.25
14	1.38	38.15	69.93	1.73
14	1.25	54.42	69.96	1.35
14	1.57	42.99	69.94	1.88
Average				**1.45**
15	2.51	61.08	69.94	2.51
15	1.1	12.17	69.96	1.41
15	1.73	1.31	69.95	2.2
15	1.07	0.23	69.95	1.1
15	1.57	7.38	69.95	1.88
15	1.04	0.84	69.97	1.25
15	1.91	65.48	69.94	2.04
15	2.35	35.83	69.93	3.01
Average				**1.93**

Table 27: Shows the measured bending length, MD and CD values for sample 1

Direction	MD (cm)	CD (cm)
A	4.30	2.30
	4.20	2.10
	4.40	2.20
	4.10	3.00
Average	**4.25**	**2.40**
B	6.50	3.20
	7.90	2.40
	6.50	3.30
	7.10	3.60
Average	**7.00**	**3.13**
C	5.90	2.50
	7.00	3.10
	4.50	2.50
	7.10	2.90
Average	**6.13**	**2.75**
D	7.30	3.10
	6.80	3.40
	6.80	3.30
	6.50	3.10
Average	**6.85**	**3.23**

Direction	MD (cm)	CD (cm)
E	6.20	3.10
	5.30	2.00
	6.50	3.10
	6.50	3.30
Average	**6.13**	**2.88**
F	5.70	2.60
	7.20	4.00
	5.80	2.90
	6.30	3.00
Average	**6.25**	**3.13**
G	7.20	3.10
	5.20	2.30
	6.90	4.00
	7.70	2.90
Average	**6.75**	**3.08**
H	6.90	3.40
	7.00	3.10
	6.20	3.00
	5.70	2.90
Average	**6.45**	**3.10**

Table 28: Shows the measured bending length, MD and CD values for sample 2

Direction	MD (cm)	CD (cm)
A'	7.40	5.30
	6.30	3.70
	9.40	3.40
	5.70	3.70
Average	**7.20**	**4.03**
B'	6.70	4.30
	6.00	3.20
	5.50	4.00
	5.80	4.50
Average	**6.00**	**4.00**
C'	5.30	4.40
	5.50	3.10
	4.90	3.00
	5.50	3.20
Average	**5.30**	**3.43**
D'	6.40	4.00
	7.30	3.40
	6.40	4.40
	7.00	3.40
Average	**6.78**	**3.80**

Direction	MD (cm)	CD (cm)
E'	7.10	3.00
	5.50	5.20
	8.00	3.20
	8.00	3.60
Average	**7.15**	**3.75**
F'	6.30	3.40
	4.70	3.50
	5.90	5.00
	6.40	4.90
Average	**5.83**	**4.20**
G'	8.10	3.80
	6.00	5.00
	7.90	4.00
	6.70	3.20
Average	**7.18**	**4.00**
H'	6.70	3.10
	6.70	4.90
	6.20	3.40
	8.20	3.40
Average	**6.95**	**3.70**

Table 29: Shows the measured bending length, MD and CD values for sample 3

Direction	MD (cm)	CD (cm)
A"	10.40	5.10
	6.90	6.40
	8.10	5.40
	10.50	6.10
Average	**8.98**	**5.75**
B"	8.20	6.90
	6.70	6.50
	9.00	6.00
	7.40	6.00
Average	**7.83**	**6.35**
C"	9.50	8.00
	8.40	6.10
	9.30	7.60
	9.80	5.90
Average	**9.25**	**6.90**
D"	7.20	5.40
	8.20	6.50
	8.80	5.40
	9.30	6.10
Average	**8.38**	**5.85**

Direction	MD (cm)	CD (cm)
E"	7.50	4.90
	7.80	6.30
	9.20	4.20
	7.50	5.60
Average	**8.00**	**5.25**
F"	7.90	6.10
	8.80	5.10
	8.10	6.10
	8.70	6.20
Average	**8.38**	**5.88**
G"	9.60	7.10
	11.90	6.20
	12.20	5.50
	8.40	8.00
Average	**10.53**	**6.70**
H"	12.60	7.20
	9.70	5.80
	12.50	6.80
	9.60	6.50
Average	**11.10**	**6.58**

Table 30: Shows the measured bending length, MD and CD values for sample 4

Direction	MD (cm)	CD (cm)
2	9.00	9.10
	10.10	7.80
	8.90	8.50
	9.60	7.50
Average	**9.40**	**8.23**
3	8.40	8.20
	11.50	7.90
	8.60	7.20
	9.50	8.00
Average	**9.50**	**7.83**
4	9.20	9.00
	13.00	7.70
	11.10	8.40
	10.80	7.00
Average	**11.03**	**8.03**
10	8.30	4.50
	11.60	4.20
	10.10	4.50
	10.70	4.90
Average	**10.18**	**4.53**
12	6.80	4.20
	5.80	4.20
	6.70	4.70
	7.00	4.00
Average	**6.58**	**4.28**

Direction	MD (cm)	CD (cm)
13	9.80	9.20
	9.40	9.00
	10.00	9.80
	11.50	7.70
Average	**10.18**	**8.93**
14	13.60	8.00
	13.50	9.50
	13.40	7.50
	13.80	8.80
Average	**13.58**	**8.45**
15	15.00	8.10
	13.30	7.40
	14.40	6.50
	14.50	7.80
Average	**14.30**	**7.45**
16	11.70	8.40
	11.00	9.30
	11.50	9.00
	12.00	8.30
Average	**11.55**	**8.75**
17	11.80	7.80
	11.30	8.40
	11.30	6.90
	10.50	7.20
Average	**11.49**	**7.96**

Images of the sample 2

Image for sample A

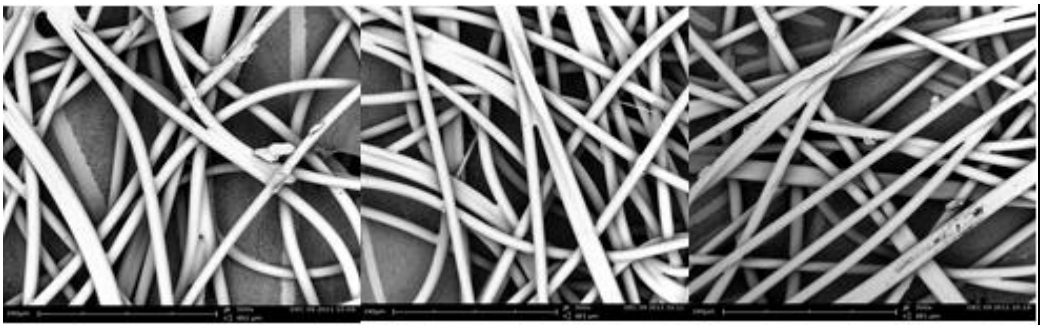


Image for sample B

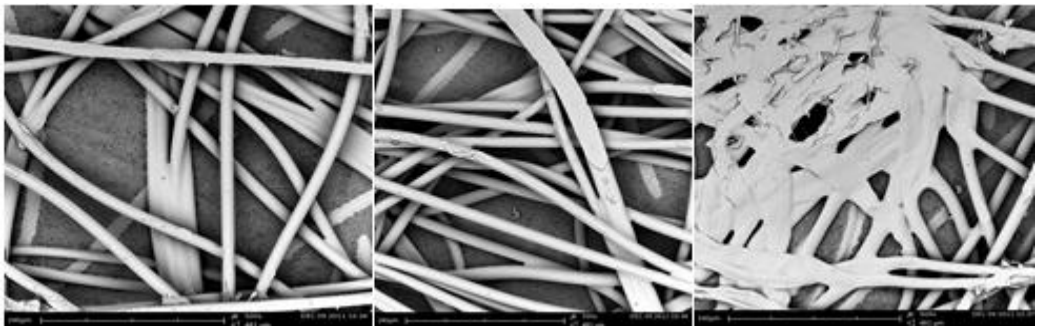


Image for sample C

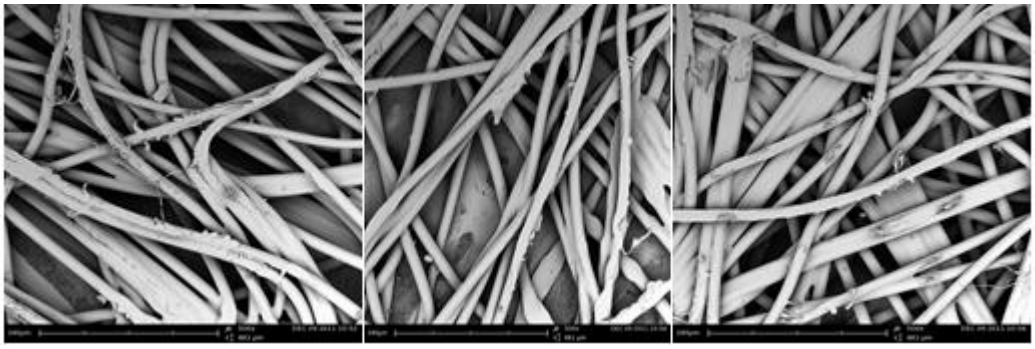


Image for sample D

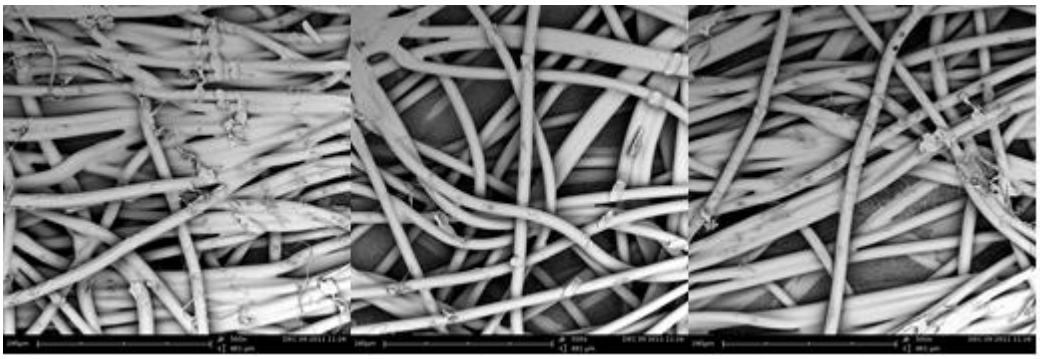


Image for sample E

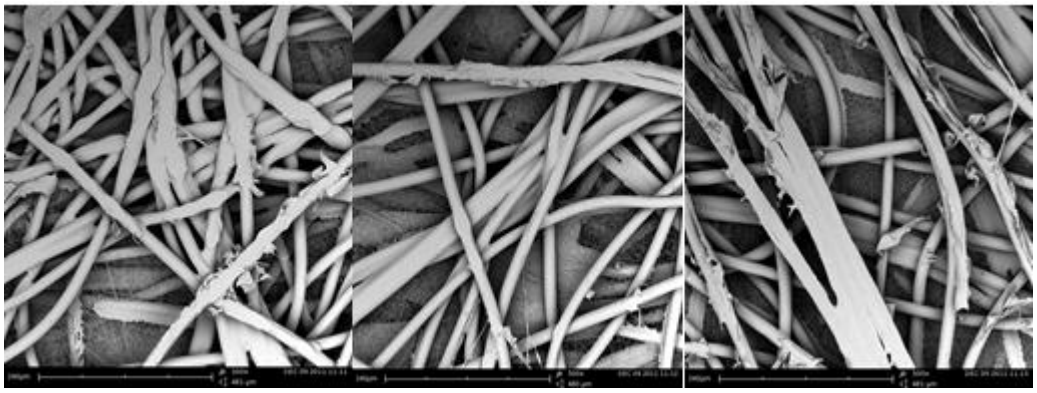


Image for sample F

Image for sample G

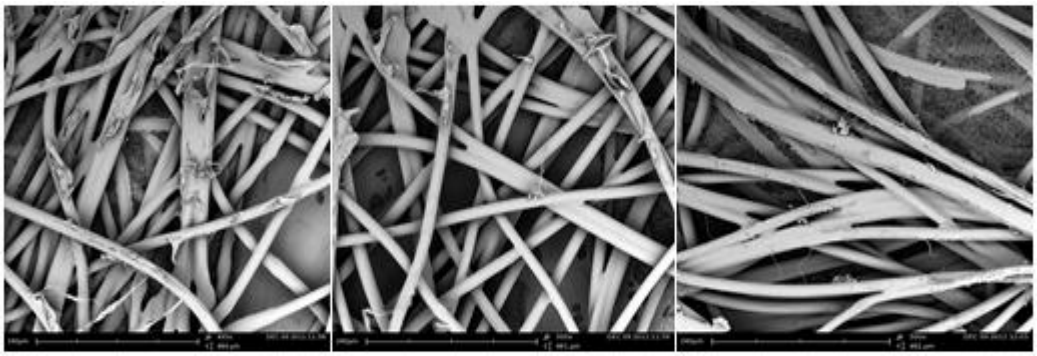
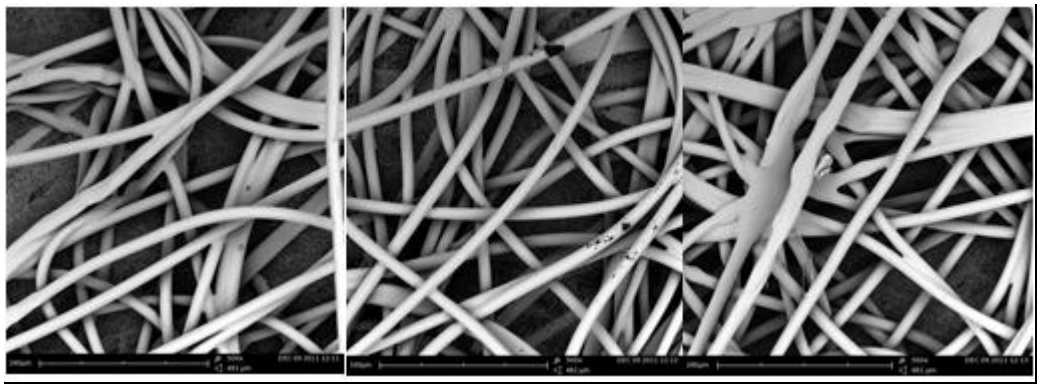
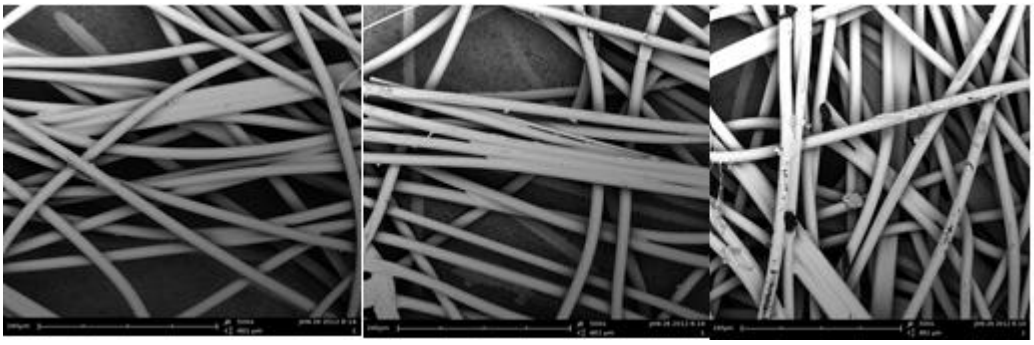


Image for sample H



Images of the sample 4

Image 1



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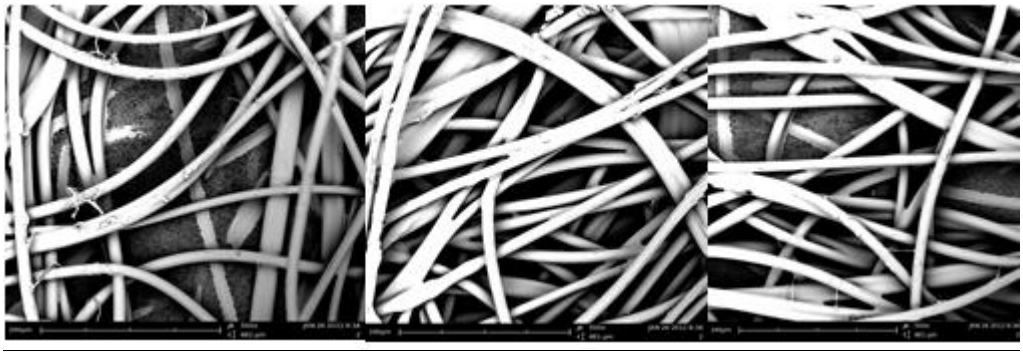

Image 3

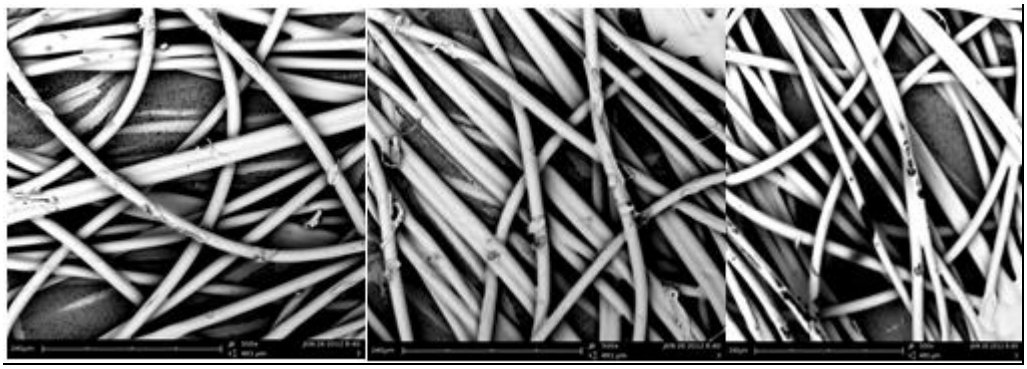

Image 4

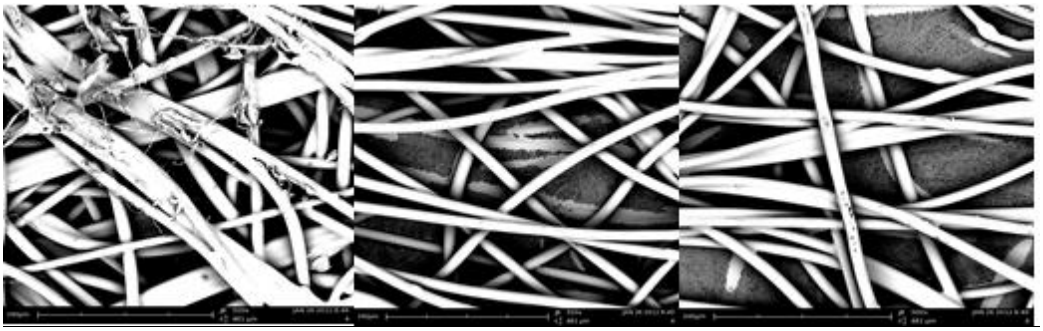

Image 6

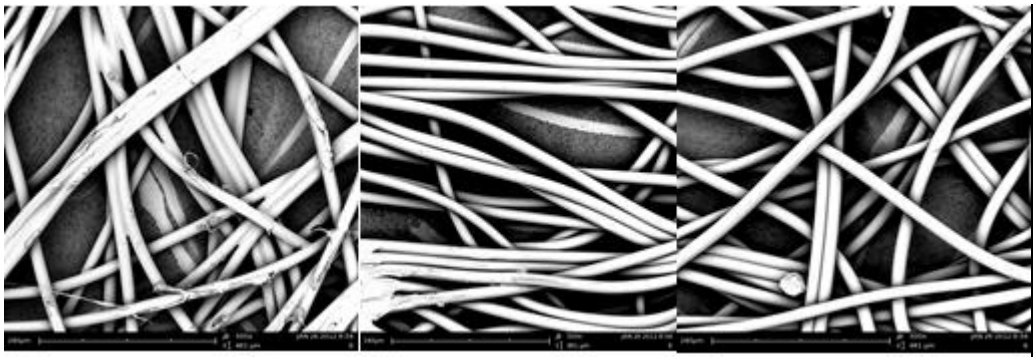

Image 7

Image 10

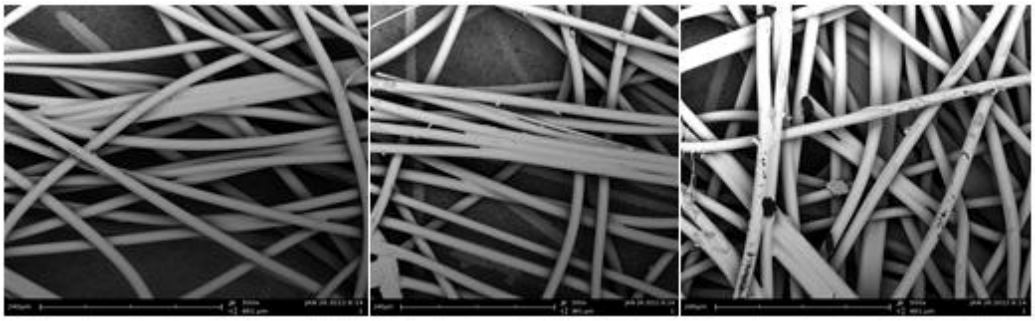

Image 11

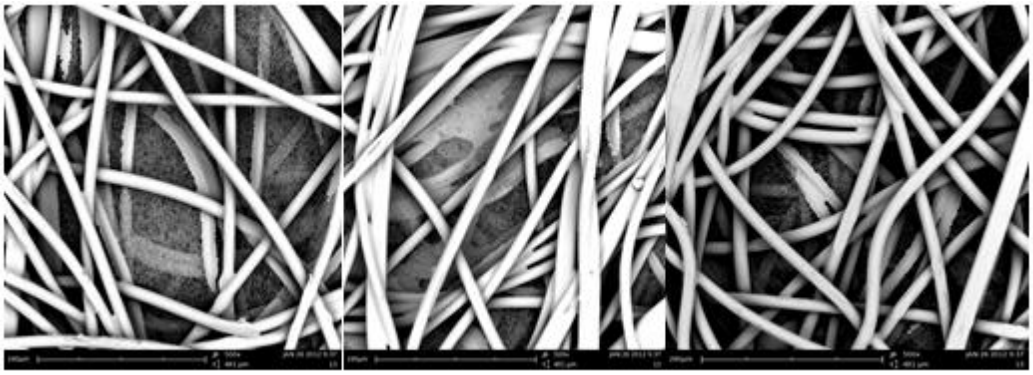

Image 14

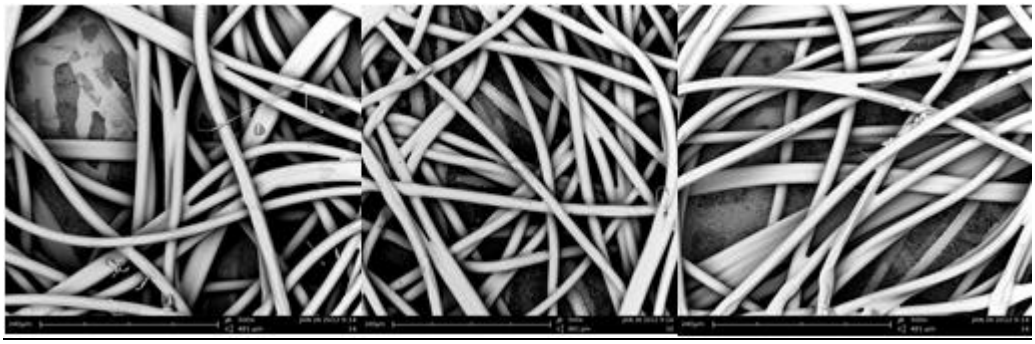

Image 15

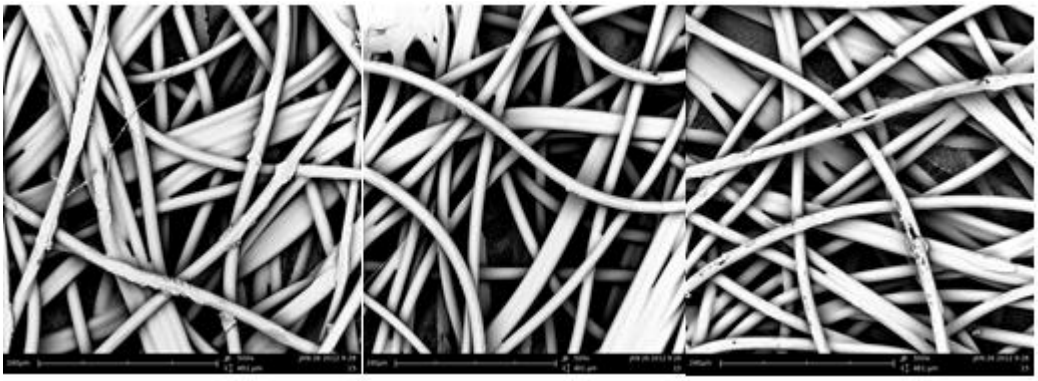

Image 16

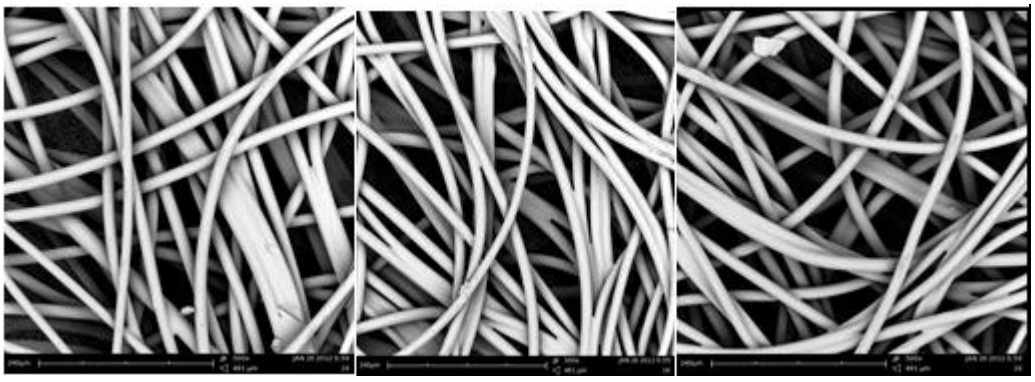

Image 17